EARTH OBSERVATIONS
PROGRAM REVIEW

4 AND 5 NOVEMBER 1969

OFFICE OF SPACE SCIENCE AND APPLICATIONS
NASA HEADQUARTERS

NOTE

This review by the Earth Observations Division was presented to NASA General Management on 4 November 1969 under the sponsorship of the Office of Space Science and Applications (OSSA). The graphics for this review and contained in this document were prepared by the Division of Program and Special Reports, Code XP. Questions concerning this review and requests for additional copies of this document should be addressed to the Earth Observations Division, Code SR, NASA Headquarters, Washington, D.C. 20546.

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4 AND 5 NOVEMBER 1969

PRESENTED BY:
EARTH OBSERVATIONS PROGRAMS DIVISION
OFFICE OF SPACE SCIENCE AND APPLICATIONS

NASA HEADQUARTERS, WASHINGTON, D. C. 20546

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Foreword

Earth Observations Programs are concerned with the use of aircraft and space to monitor the Earth's environment and its natural resources. These programs include the use of space technology for Meteorology and Earth Resources Survey. Meteorological satellites represent an already proven technology which has reached operational status. Earth Resources Survey, on the other hand, is still in an early stage with the first dedicated research satellites under development but not yet flown. Earth Resources Survey includes applications to the disciplines of agriculture, forestry, geology, hydrology, geography, and oceanography.

This report reviews NASA's current programs for the development of capabilities for the survey of Earth resources and the monitoring of Earth's weather, and it discusses the Supporting Research and Technology which contributes to the advancement of these capabilities and to their fruitful application. Future programs are also discussed as illustrations of the range of missions and systems available as options and to provide insight into NASA's integrated approach to Earth Observations. Discussion of these potential programs does not imply official acceptance or approval by NASA General Management. Specific program plans to be executed will be the result of careful review and consideration of all program needs within the OSSA, as approved by General Management, and within the framework of program authorizations established by the President and the Congress.

John E. Naugle

Dr. J. E. Naugle
Associate Administrator,
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INTRODUCTION TO THE OFFICE OF SPACE SCIENCE AND APPLICATIONS EARTH OBSERVATIONS PROGRAMS REVIEW

Presented by
Mr. Leonard Jaffe

The great strides which have been made in space technology during the last decade now provide us with a new view of our planet Earth. As illustrated in Figure 1, we no longer are limited to a microcosmic view of small pieces of the Earth and atmosphere at a time, but can now, from a platform physically removed from the Earth, observe the entire planet. This is of particular interest since we can now view the Earth as a largely closed ecological system, which it essentially is. We now have the technological tools to begin to address some of the broader problems of understanding, modeling and, eventually, managing both the environment and resources existing on the planet Earth.

One might even say, from this distant view of the planet Earth, that there is some reasonable analogy to the Earth being a manned spacecraft moving in space with its own crew and subsystems. This view is described in an evocative narration prepared by Mr. Arthur C. Clarke for a forthcoming television documentary: "The Promise of Space." While the description is somewhat fanciful, some of the insights are useful and, with your permission, I would like to read it.

Figure 1

This is the Spaceship Earth. Destination: Unknown.

The crew is approximately three billion. It has no overall captain, but a large number of first mates who do not always agree.

They rule from many command modules.

It is a beautiful ship...
...but it is in grave trouble. There is always a mutiny going on somewhere...

Some decks are hopelessly overcrowded, and the food is running low.

The plumbing and air conditioning are unreliable.

Some parts are not as well built as they might have been.

The waste disposal system leaves much to be desired.

And there is fire down below...

Often its life support systems have been poorly maintained.

Not all its crew can be kept busy - or productive.

But we can't abandon ship. There are not enough lifeboats to go around. The nearest land is distinctly hostile. A nice place to visit, but who would want to live there.

We are here - three billion of us - and millions more coming each year. We are signed on for the duration of the voyage. We alone, the crew and its mates, must decide if Spaceship Earth is to become a tired wornout derelict, drifting lifelessly on the seas of space...

...whose problems are so profound that the crew resorts, each generation through the ages, to destruction in pursuit of peace.

It is from space that, for the first time, we are able to see Earth as a single entity, whose problems are shared by all mankind.

To meet the challenges of today's life on Earth - we must use the tools of space...the new astronautic sciences, the new technology of our electronic fantasies.

> Because these tools are new...and strange...only a few men yet understand their purpose - fewer still, their promise. Some even fear them, as new things are always feared. But not to use them would be worse than folly - for with their aid, we can overcome today's torment on Earth.
>
> Only by using the new technology and sciences have we been able to put man in his cosmic environment. Now... only by applying these same talents and tools, will be understand, fully, the true promise of space.*

Here we have heard an imaginative description of some of the Earth-bound problems - resource problems and people problems. Can we be more explicit in identifying the social and economic problems to which Earth observations may make a beneficial contribution? Some of these are referred to in Figure 2 and include assuring: adequate world food supply, satisfactory water quality and availability, an adequate supply of mineral resources, efficient use of land, well-planned urban development, and control of pollution and the understanding and control of our atmospheric environment. Certainly Earth observations from satellite platforms will not, of itself, solve these problems and no intent is made here to imply that this is so. However, based on the work which has been accomplished thus far, it seems clear that significant contributions towards their amelioration, and in some cases, eventual solution, may soon be made.

SOCIAL AND ECONOMIC PROBLEMS

TO WHICH EARTH OBSERVATIONS MAY MAKE A BENEFICIAL CONTRIBUTION

- FOOD SUPPLY
- WATER QUALITY AND AVAILABILITY
- MINERAL RESOURCES
- LAND USE
- URBAN DEVELOPMENT
- POLLUTION - AIR, WATER, LAND
- ATMOSPHERIC ENVIRONMENT

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Figure 2

One may ask what we mean by utilization of Earth observations for assistance in solving social and economic problems. The answer is best illustrated in Figure 3 (over) where we see that observation of the Earth is only the beginning. We must then proceed to understanding, which can enable us to perform modeling, then to prediction and then to management and modification. This progression of capability is inherent in all the activities of Earth observations. This evolution of capability is illustrated in the figure with some typical examples that can be envisioned for the short-range, mid-range, and long-range planning period. For example in the short range, based largely on the early Earth Resources Technology Satellites (ERTS), it will be possible, in the category of observations, to conduct routine thematic monitoring of the land and the sea. As we progress in what is termed the Earth Physics area, we expect to develop improved, world reference systems; this capability will depend on understanding and modeling. In the mid-range period, it should be possible to develop comprehensive models for the atmosphere, the dynamic Earth, the oceans and the land. It is anticipated that utilization of the comprehensive atmospheric models, in this mid-range period, can lead to more accurate 15-day weather forecasts. In the case of the oceans and land, it is expected that predictions for use in managing food production, controlling pollution and natural disasters, as well as in managing resources and transportation activities could be available. It could also be possible to initiate regional experiments in the management of natural resources such as water. Perhaps, in the longer range, experiments in hemispheric-scale weather modification could be anticipated.

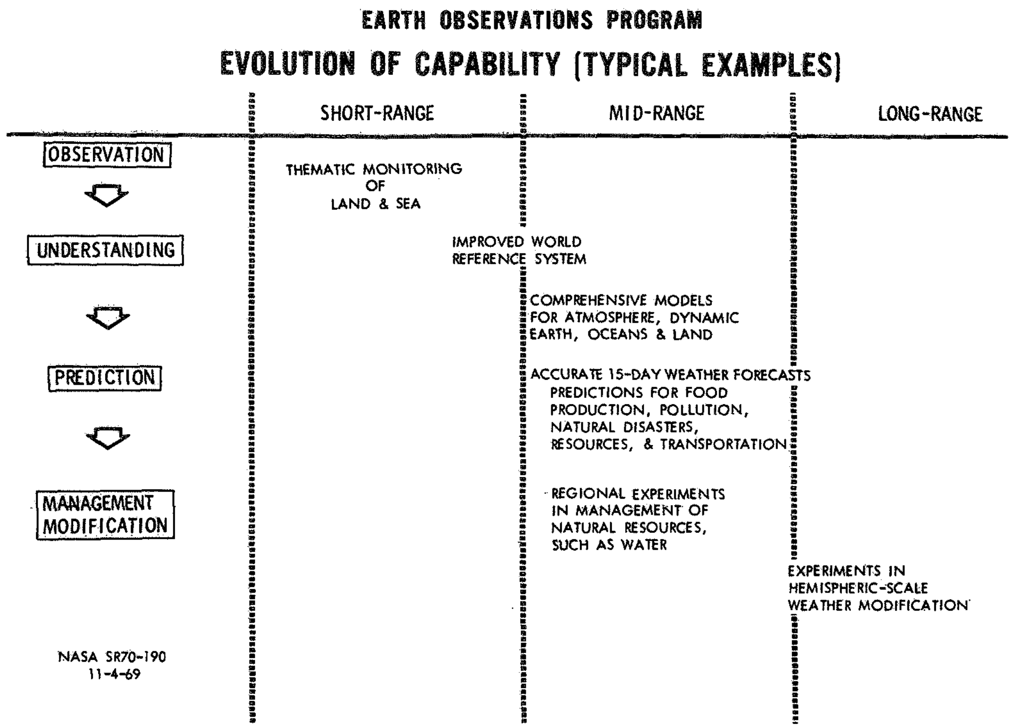

Figure 3

It is, however, not absolutely necessary that each of these steps of observation, understanding, prediction and management/modification proceed in a sequential manner nor that we attain the last of them to realize benefit. Each of these steps can be considered a useful end goal unto itself and certainly some degree of management can be exercised with only a knowledge of the current status derived from observation without the benefit of understanding and prediction.

The significance and suggested priority of this activity within the national space program is illustrated by the quotations in Figure 4. In the Space Task Group Report to the President (September 1969) the first objective of the national space program was given as to "increase utilization of space capabilities for services to man through an expanded space applications program." In the report of NASA to the Space Task Group, this was gone into in more detail where the Earth Resources Survey goal was stated as: "To establish a capability for responsible management of the Earth resources and human environment." The mandate is clear.

"INCREASE UTILIZATION OF SPACE CAPABILITIES FOR SERVICES TO MAN, THROUGH AN EXPANDED SPACE APPLICATIONS PROGRAM".

FROM: THE POST-APOLLO PROGRAM: DIRECTIONS FOR THE FUTURE SPACE TASK GROUP REPORT TO THE PRESIDENT, SEPTEMBER 1969

"TO ESTABLISH A CAPABILITY FOR RESPONSIBLE MANAGEMENT OF THE EARTH'S RESOURCES AND HUMAN ENVIRONMENT".

FROM: AMERICA'S NEXT DECADES IN SPACE -- A REPORT FOR THE SPACE TASK GROUP, PREPARED BY NASA, SEPTEMBER 1969

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11-4-69

Figure 4

We have for the purpose of this presentation divided the Earth Observations Program into two parts: One on the Meteorology Program which will be given by Dr. Tepper following the other on the Earth Resources Survey Program.

EARTH RESOURCES SURVEY PROGRAM

Presented by
Mr. Leonard Jaffe

I. INTRODUCTION

We have alluded to the broad economic and social problems which may be addressed via remote sensing (observations), and we will assume familiarity with the disciplinary areas of agriculture, forestry, hydrology, geography and oceanography with which Earth resources survey is concerned. The basic objectives which NASA adopts in order to provide the maximum assistance of space technology in these problem and disciplinary areas are summarized in Figure 1. Certainly, NASA which understands best the capabilities of space technology, must play a strong role in defining those real world problems to which it seems that a beneficial contribution can be made by remote sensing from space. It is also necessary to conduct research in remote sensing to establish signature recognition criteria and to develop sensors, subsystems, experimental spacecraft and launch vehicles. It is also necessary to determine the scope and configuration of total future operational systems including spacecraft, aircraft and ground segments. In addition, it is important to develop data handling techniques which can assure that data will be made available to experimenters and users in a number of different disciplines; in particular, it is more efficient to develop, if feasible, a single set of data handling equipment which can serve the needs of several disciplines. Perhaps one of the most significant aspects of NASA activity is to assist user agencies in developing a community of experts prepared to utilize space-derived or aircraft-derived remote sensing data.

EARTH RESOURCES SURVEY PROGRAM

NASA OBJECTIVES

- DEFINE REAL WORLD PROBLEMS TO WHICH SPACE TECHNOLOGY CAN MAKE A BENEFICIAL CONTRIBUTION
- DETERMINE PERFORMANCE OF REMOTE SENSORS, ESTABLISH SIGNATURE RECOGNITION CRITERIA
- DEVELOP SENSORS,SUBSYSTEMS, AND EXPERIMENTAL SPACECRAFT, ALONG WITH EFFICIENT MEANS FOR GETTING INTO ORBIT.
- DETERMINE SCOPE & CONFIGURATION OF OPERATIONAL SYSTEMS (INCLUDING SPACECRAFT, AIRCRAFT, AND GROUND SEGMENTS)
- DEVELOP DATA HANDLING TECHNIQUES
- ASSIST USER AGENCIES IN DEVELOPING A COMMUNITY OF EXPERTS PREPARED TO UTILIZE SPACE-DERIVED REMOTE-SENSING DATA.

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Figure 1

An overall view of the Earth Resources Survey (ERS) Program is illustrated in Figure 2. The program may be divided into three main groupings, namely, the aircraft program, the spacecraft program and the supporting research and technology program. The ERS Program will be described by addressing these three general areas in sequence. It should be noted that in Figure 2 distinction is made between the approved and proposed programs.

II. THE AIRCRAFT PROGRAM

The ERS Aircraft Program has produced most of the experimental data used to date. It is the facility we use to define and develop remote sensor systems. The aircraft provides a flexible large platform on which we can carry developmental sensors in combinations for the required intercomparison of performance and utility (Figure 3). The aircraft observation program has been

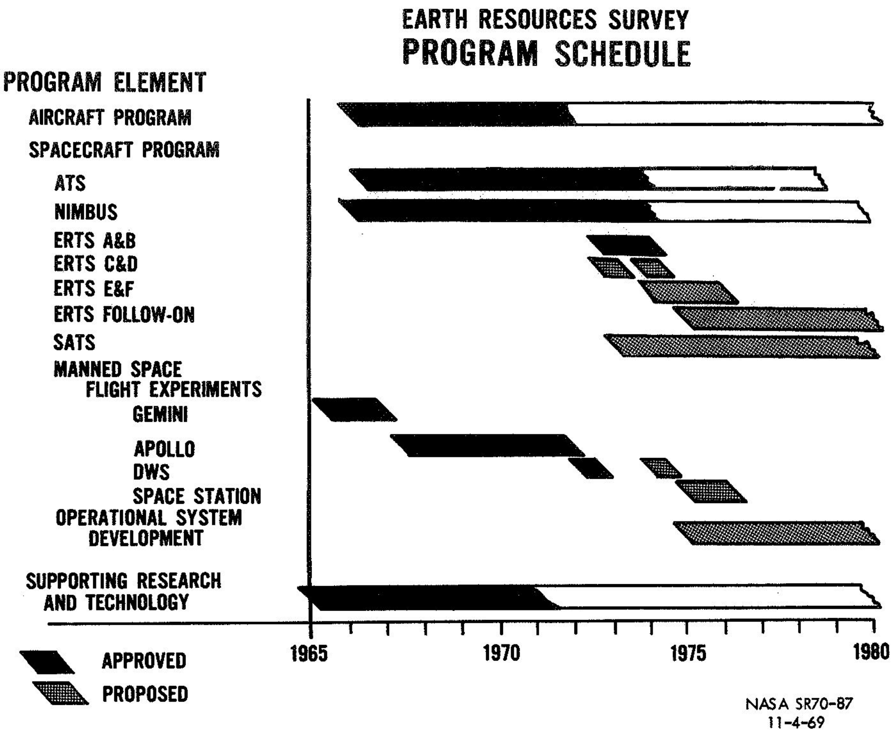

Figure 2

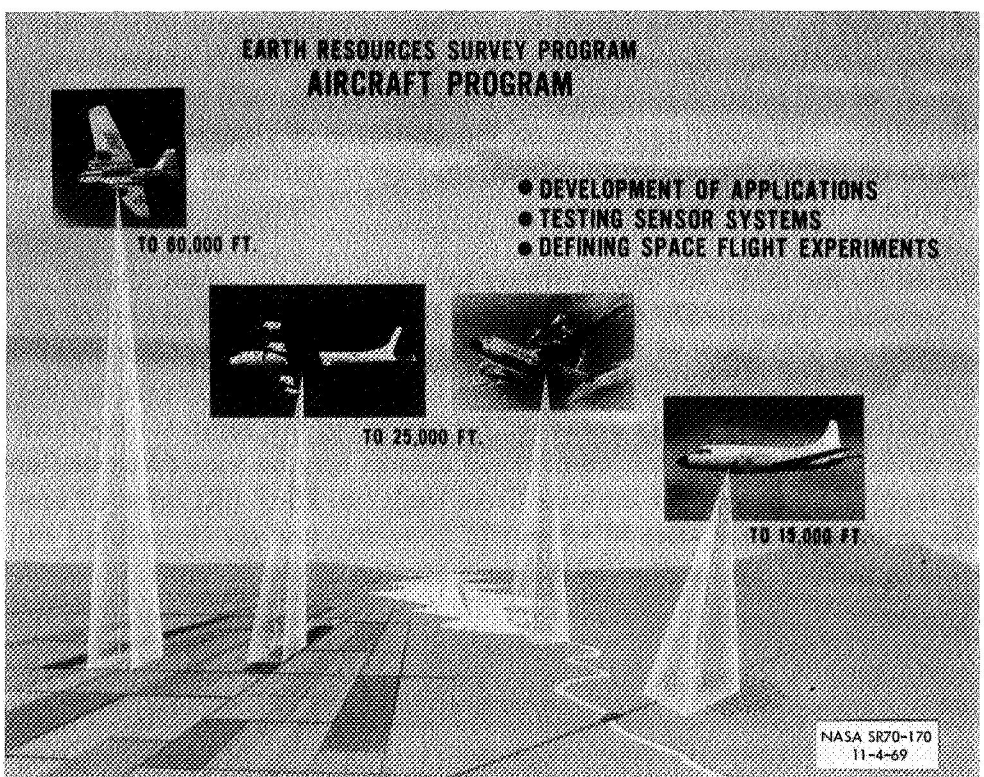

Figure 3

executed in cooperation with Federal user agencies, including the Departments of Agriculture, Interior, Commerce and Navy and other qualified investigators so as to provide the broadest base of data possible within the resources available.

The remote sensors that are being evaluated for these disciplines are (a) those that actively "illuminate" targets and receive reflected radiation, and (b) those that operate as passive monitors of natural and cultural emissions or reflections from the earth's surface. With these types of sensors it is possible to obtain multispectral data of terrestrial phenomena for disciplinary analysis. Rather than going directly to instruments in spacecraft, user agencies and cooperating scientists are obtaining precursory data from multispectral instrumentation in aircraft. The data is used to evaluate the sensors over specific instrumented test sites and to develop a solid foundation for scientific observational and interpretive techniques, in preparation for the advent of earth resources space missions.

The airborne program has been subdivided into two phases; a low to medium altitude phase and a high altitude phase. Currently, in the first phase, there are three operating spacecraft: a Convair 240, an Electra P-3A, and a Hercules C-130B. Extensive modification internally and externally has converted these aircraft into excellent multispectral airborne platforms for evaluation of a variety of sensors.

The National Academy of Sciences (NAS) Space Applications Summer Study at Woods Hole, Massachusetts, 1967-68, suggested the use of high-altitude platforms including a jet aircraft. The principal advantages of high-altitude flights are in simulating conditions nearer to those which can be expected from an orbiting spacecraft and in permitting assessment of the roles which may be effectively filled by aircraft in future operational aircraft-spacecraft mixed systems. By flying remote sensors at altitudes above about 90 percent of the earth's atmosphere, we extend the established range of the sensors' performance capabilities, as well as verify our data-handling and analysis techniques. The additional data on the variation of signal-to-noise ratio with altitude permit us to do better remote sensor planning, and to define in a more realistic manner the input specifications for the space sensors.

An agreement signed by the U.S. Air Force allows for part-time use of an RB-57F, assigned to the Air Weather Service. The RB-57F (Figure 4) can fly at altitudes in excess of 60,000 feet. (NASA is programmed for 200 hours of flight time on this aircraft during each three-month period.) The RB-57F aircraft has conducted a number of earth resources flight since June 1969. The sensors are installed on a pallet which is easily detached for servicing the sensors. Because of the inaccessibility of the pallet in flight, operation of these sensors may be viewed as an "unmanned" mode. Sensors presently located on the pallet include (from top): a RS-7 (IR) infrared scanner-imager, an IR spectrometer and radiometer, two RC-8 metric cameras, and six Hasselblad multiband cameras. Microwave sensors are located in the nose section of the aircraft.

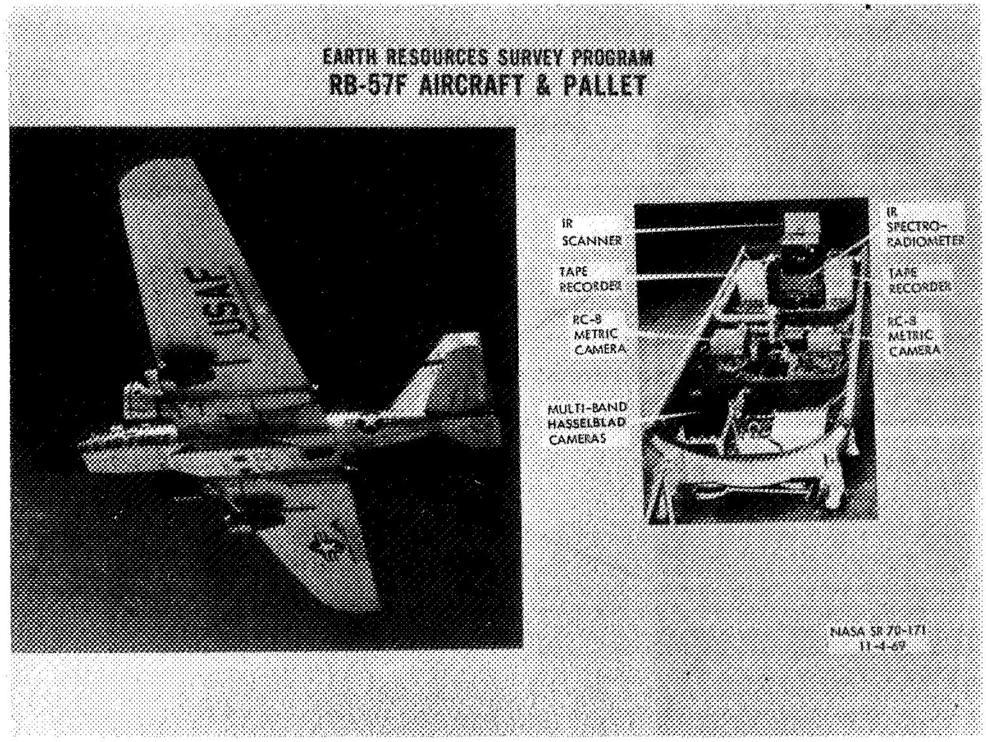

Figure 4

After the first two years of experimentation it became obvious that the Convair 240 and the Electra P-3A aircraft could not fulfill the complete low-medium altitude test requirements of the participating Earth scientists for experimentation with the sensors over many different test site areas. Consequently, a Lockheed C-130B, Figure 5 (over), was obtained to replace the Convair 240. The C-130B aircraft provides a considerably greater payload, and performs at greater ranges and at higher altitudes. The sensors that are currently being integrated into this aircraft are being transferred from the Conviar 240. The C-130B also provides a large internal volume for instrument installation and for personnel. Since essentially all instrumentation is accessible during flight, this aircraft may well be termed a "flying laboratory" offering a "manned" mode of operation. As a result of the unique arrangement of the tail section ramp, it is possible to load and off load self-propelled vehicles into this aircraft. Consequently, the use of a specially-equipped mobile ground-truth vehicle is to be included as part of the sensor verification equipment on this aircraft. The ground truth vehicle will be used to provide ground instrumentation at test sites that do not contain sufficient field equipment for collecting the correlative data required for proper sensor evaluation.

The interior view of the C-130B are shown in Figure 5. The Systems Manager's console, where the data collection is controlled, contains a tape recorder and other data handling equipment. The stove-pipe object is a sky radiance tube for calibrating the 24-channel multispectral scanner (see page 38, Figure 47) being currently built for installation in June 1970. The scanner will probably be one of the most significant research instruments contained in our program. Camera windows seen in the lower left are for the two metric and the six Hasselblad multiband cameras.

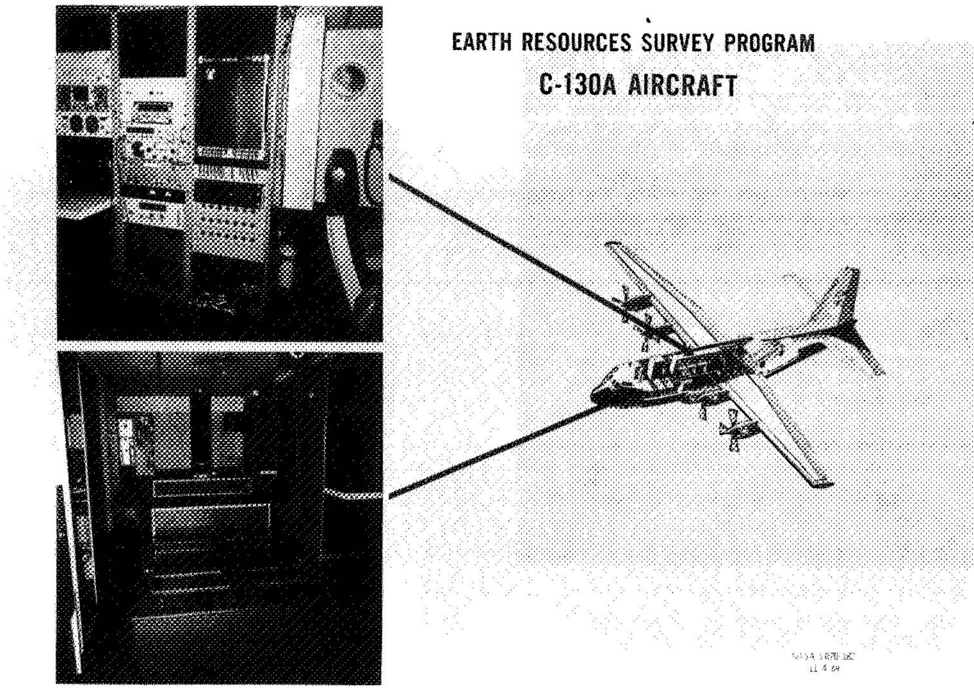

Figure 5

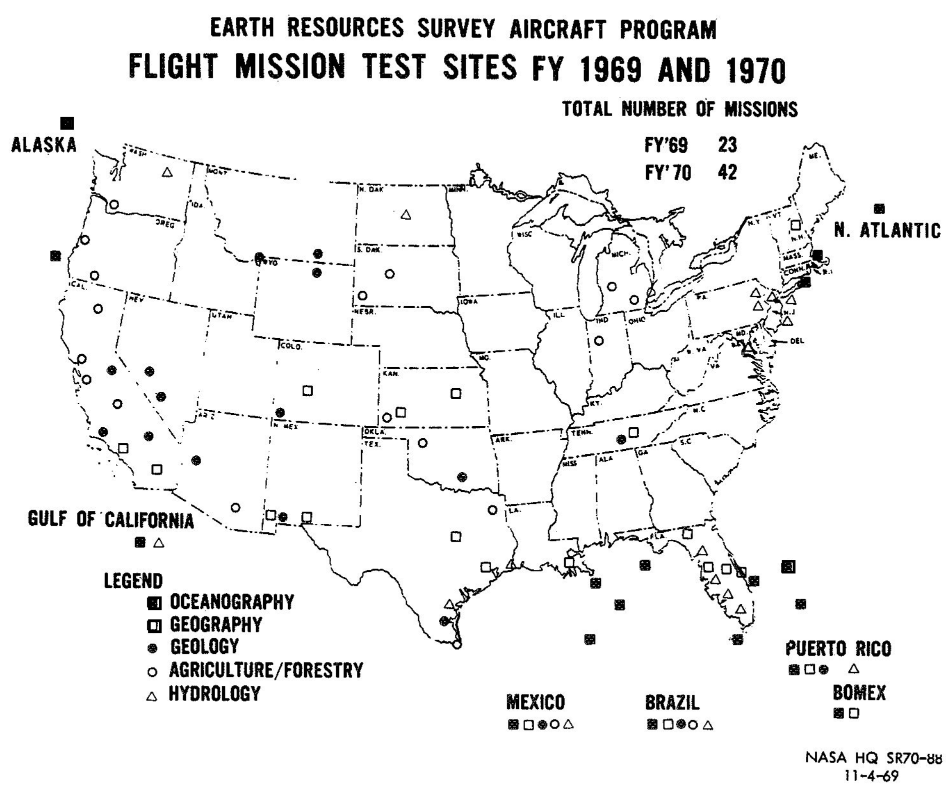

Figure 6

Figure 6 shows the Earth resources test sites overflown in FY 1969 and those that will be overflown by the end of FY 1970. In FY 1969 NASA Earth resources aircraft conducted 23 missions while in FY 1970 we expect to conduct 42 missions. A typical mission overflies from three to six test sites on an average. Thus a number of disciplinary scientists are usually furnished with research data after each mission is completed. During the coming year, it is planned to move from individual test sites toward a regional test area concept incorporating, perhaps, a number of the presently designated test sites. Typical candidate areas for this regional concept include California, the Gulf Coast and one or more estuaries of the northeastern United States.

In addition to test sites within the continental U.S., NASA has initiated a cooperative test site research program with two Latin-American countries. The test sites overflown during CY 1969 in Mexico, and Brazil, are shown in Figure 7. In Mexico the NASA ERS P-3A aircraft overflew six multidisciplinary test sites; in Brazil five test sites were overflown. While in South America for the Brazilian program, we were also requested to obtain some data in Argentina in support of the International Biological Program. Figure 7 shows each test site's approximate location and the discipline involved in the investigation. Both the user agencies and NASA have also provided training in remote sensing for foreign nationals. This initial and limited foreign cooperative program is illustrative of the means by which other countries may eventually be assisted towards participation in ERS activity. This type of experience may be of considerable use in preparing for the international impact of anticipated Earth Resources Technology Satellite data.

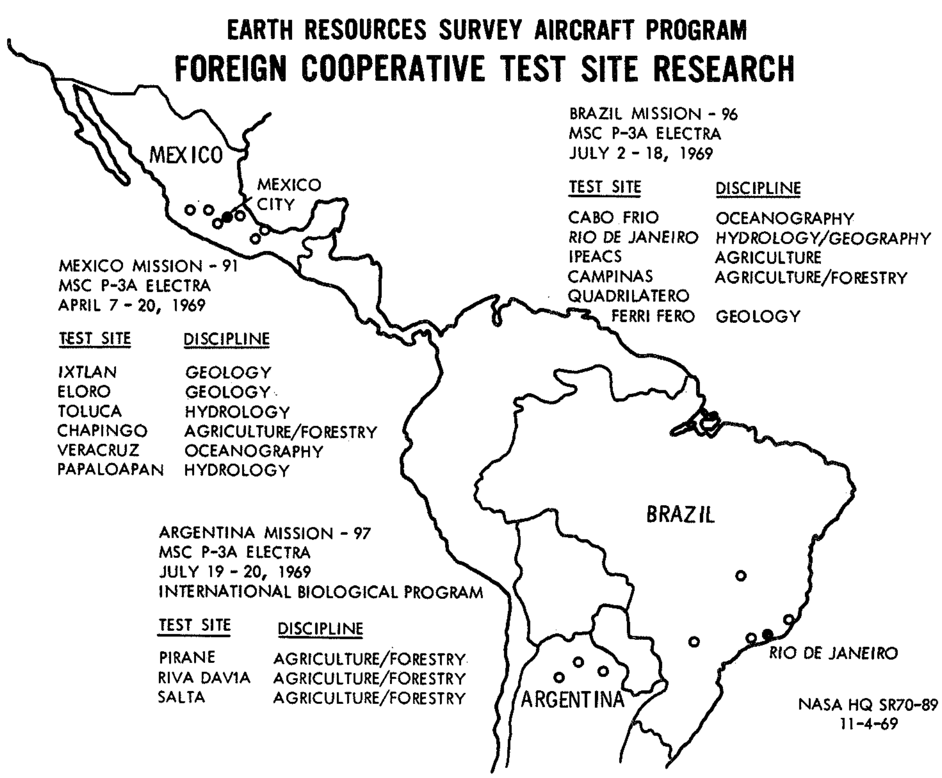

Figure 7

An example of data obtained over Mexico is shown in Figure 8. This is a color photograph of the Chapingo Agriculture Test Site about 25 miles northeast of Mexico City. (Note that although this text may refer to color, only black and white reproductions are printed.) It is a good example of imagery used for crop identification. Examples of crops shown are alfalfa, peas, barley, oats and wheat. Differences in stages of growth are distinguished by variations in shades of green. Drainage in cultivated fields can also be distinguished. (This photograph was taken by a metric camera from an altitude of 4,000 feet.). The Agriculture Research Institute of Mexico may be seen in the lower right corner of the image.

An example of data obtained over Brazil is shown in Figure 9. This is a color IR photo of the Campinas Agriculture Test Site about 250 miles west of Rio de Janeiro. The Central Research Experimental Farm of the Campinas Agronomic Institute is considered to be the most suitable area for studies of coffee, soils, and natural vegetation. With this type of film ("color IR") red is indicative of healthy vegetation while yellow is indicative of soil condition. Some growth can be seen. The green fields have been plowed and seeded, with variations in green indicative of the condition of the soil. Traces of pink in these newly plowed fields indicate new healthy growth. Traces of blue in the new fields are indicative of water. (The photograph was taken with a metric camera from an altitude of about 5,000 feet.)

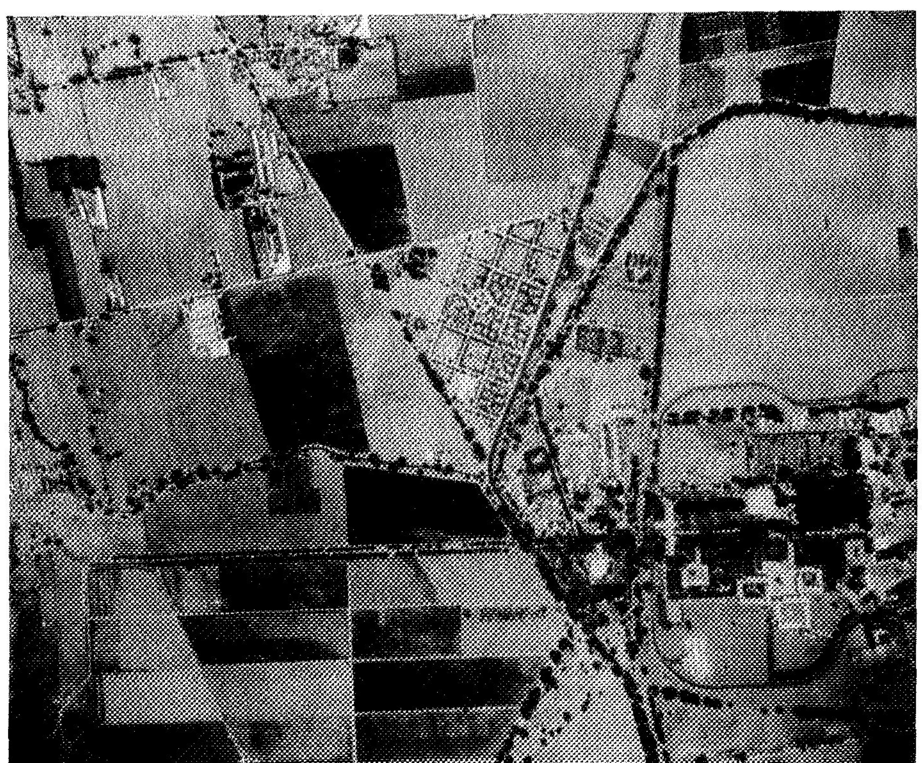

Figure 8

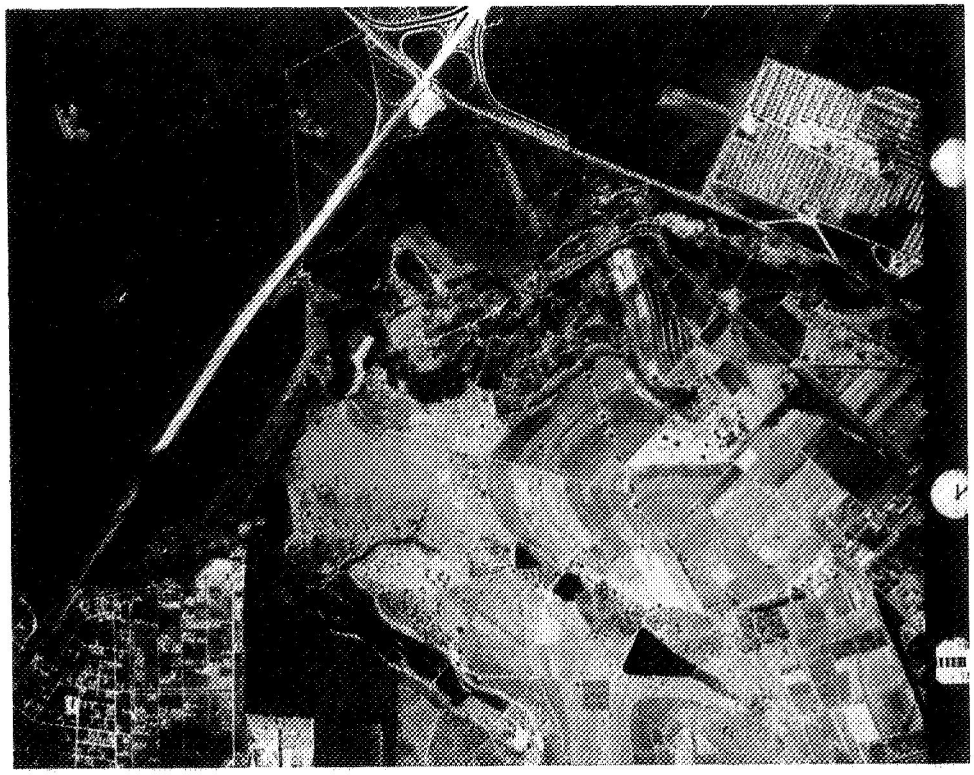

Figure 9

Figure 10 summarizes the status of activities in the present foreign cooperative program with Brazil and Mexico. Data has been disseminated and reviewed. Preliminary progress reports by Mexican investigators have been received and reports from Brazil are due this coming January. Final reports are expected later in 1970. Both Mexico and Brazil are planning to operate their own remote sensing aircraft late in 1970 or early in 1971.

EARTH RESOURCES SURVEY PROGRAM

FOREIGN COOPERATIVE PROGRAMS WITH MEXICO AND BRAZIL

EARTH RESOURCES AIRCRAFT MULTI-DISCIPLINARY FLIGHTS
- MEXICO, APRIL 1969 (SIX TEST FLIGHTS OVERFLOWN)
- BRAZIL, JULY 1969 (FIVE TEST FLIGHTS OVERFLOWN)

DATA DISSEMINATION AND REVIEW
- NASA AND USER AGENCIES
- MEXICAN INVESTIGATORS, JUNE 1969
- BRAZILIAN INVESTIGATORS, SEPTEMBER 1969

PRELIMINARY PROGRESS REPORTS BY FOREIGN INVESTIGATORS
- MEXICO, SEPTEMBER 1969
- BRAZIL, JANUARY 1970

FINAL REPORTS BY FOREIGN INVESTIGATORS
- MEXICO, JUNE 1970
- BRAZIL, SEPTEMBER 1970

BRAZILIAN AND MEXICAN AIRCRAFT OPERATIONAL
- LATE 1970 OR 1971

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Figure 10

The recent disaster caused by the passage of hurricane Camille over the Gulf Coast provides a notable example of the potential for assistance with the existence of aircraft equipped with remote sensors could provide for damage assessment and emergency planning. The damaged coast was overflown by the NASA Convair at 5,000 feeet altitude the day after the storm. A typical set of color photographs of Camille-damaged terrain is shown in the Figures 11, 12 and 13. Figure 11 is a view of the Gulfport, Mississippi harbor.

Overall, approximately 80 % of the port's storage and administrative facilities were totally destroyed. The small craft harbors on either side of the main harbor were damaged extensively. A large barge can be seen resting on top of the seawall just west of the main harbor. A highwater mark of approximately 23 feet above mean sea level was observed in the Louisville and Nashville Railway Terminal. Debris in the western portions of the photograph and just inland from U.S. 90 is mainly from the storage areas at the main harbor. The circular tanks just east of the main harbor are all that remain of the famed Gulfcoast Marine-land. Three ships can be seen to be beached in the harbor.

Figure 12 covers a section of the Mississippi Gulf Coast near Pitcher Point, Long Beach, Mississippi. This section of coastline is fronted by a man-made beach and a step-type concrete seawall that is approximately 10 feet high. Highway U.S. 90 parallels the seawall. Several features are distinguishable in this photograph: (1) a zone of 100% destruction of man-made cultural structures lies just inland from U.S. 90, (2) a debris line, deposited by the storm tide, is apparent and generally conforms to a geologic elevation contour of approximately 18 feet above mean sea level, and (3) several motels, a shopping center, a drive-in theater and various residences are totally destroyed (right center). Figure 13 is an enlargement of the shopping center and motels shown in Figure 12. In the original master images, tornado-like tree-leveling effects could also be detected inland, near the periphery of the storm.

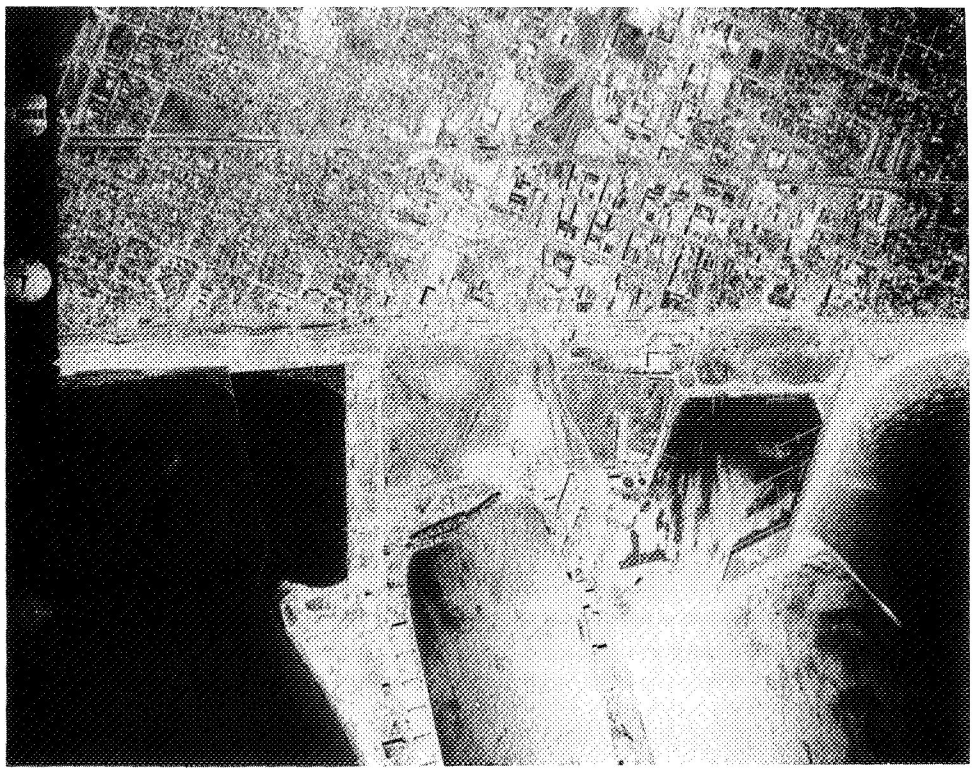

Figure 11

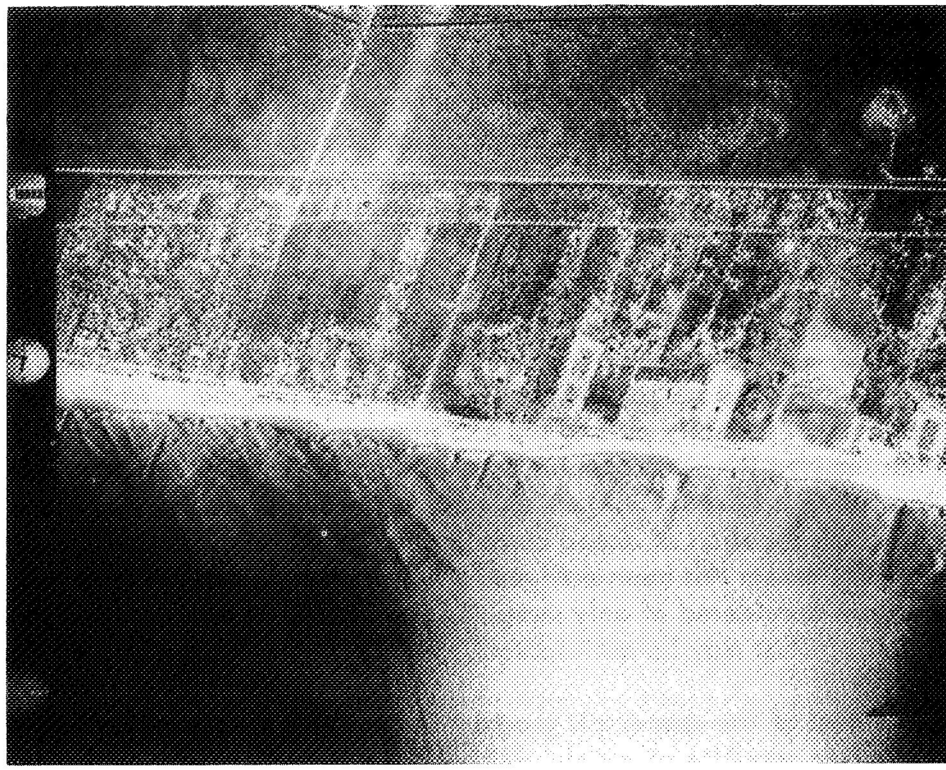

Figure 12

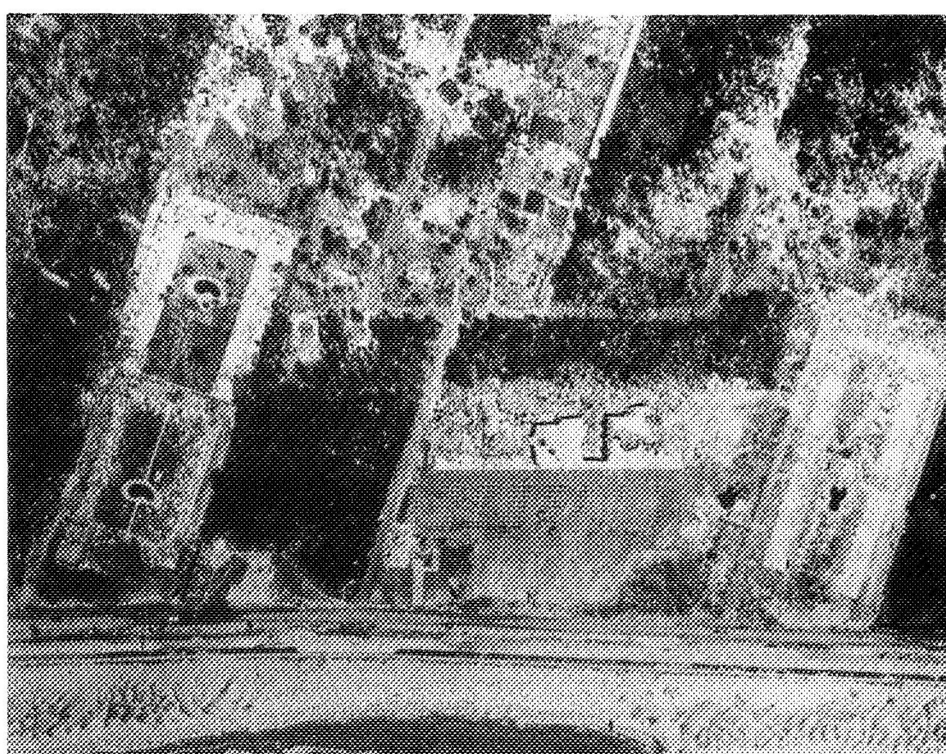

Figure 13

This information was supplied to the Corps of Engineers (in Mississippi), to the Office of Emergency Planning, and the Small Business Administration for whatever use they would make of it. We will ask them periodically what value they found in the data. As an internal exercise, the Manned Spacecraft Center is comparing these data with previously obtained aircraft data supplied by the Corps of Engineers and Manned Spacecraft Center will turn out a technical report on the impact of Camille on these shoreline features.

III. THE SPACECRAFT PROGRAM

Let us now turn to the spacecraft portion of the ERS program. While the ATS and Nimbus satellites are not formally part of the ERS program, they have provided data of interest which has assisted the evolution and implementation of ERS. In particular, the Nimbus High Resolution Infrared (HRIR) sensor data has provided ocean temperature data, and hence, implicitly, the location of ocean currents such as the Gulf Stream. Some land imagery from the same sensor has been analyzed by geomorphologists. While this imagery has been at resolutions considered of only marginal use in ERS, it has provided some encouraging indications of what may be anticipated from the higher-resolution, dedicated ERS satellites.

The main thrust of the spacecraft program is the Earth Resources Technology Satellites (ERTS) series, the first satellite of which, ERTS-A, is planned for launch during the first quarter of 1972. Let us now look at the approved program for ERTS-A & B. The objectives shown on Figure 14 include the principal mission goals for ERTS-A & B. It is expected that analysis of the data acquired by ERTS-A & B will provide significant information for each of the listed objectives. Our background studies and the experimentation which we have conducted in the laboratory, in the field, and by aircraft over the past several years, as well as analysis of photography acquired by the Gemini and Apollo flights, provide a substantial basis for expecting successful achievement of these objectives by ERTS-A & B. The flow of data from ERTS-A & B will provide essentially raw (uninterpreted) data to the user community which will, in turn, produce the products listed in the chart. The data will also provide a means to further develop and refine systems to extract and apply the space-acquired information. As a consequence of the extended time of mission operation, it should be possible to accurately assess the performance of the sensors and ancillary data transmission and reproduction systems. The flight tests information gained during the ERTS-A & B missions is expected to provide extensive systems engineering data for the refinement of follow-on missions. Products to be developed by the user community will include: photo-images at about a 1:1,000,000 scale, photo-images of large geological features, land-use plots, coastal area plots, and snow cover plots. These can all be derived from imagery obtained at the spectral and spatial resolution performance capabilities specified for the ERTS-A & B sensors. The repeated coverage each 17 days provided by the ERTS-A & B orbits will allow additional information to be extracted about time-dependent phenomena such as the variations in snow cover which may be relatable to water run-off rate and abundance as well as the seasonal variations in color and tone relating to agriculture and forestry phenomena.

Figure 15 shows the principal performance parameters of the sensors proposed for ERTS-A. The selection of these sensors reflects a careful consideration of the current state of sensor technology, the scheduled launch date of ERTS-A, and the data use and format requirements of the user community.

EARTH RESOURCES SURVEY PROGRAM
ERTS A&B OBJECTIVES

- DETERMINE USEFULNESS AND OPERATING EFFICIENCY OF SYSTEM
- FLIGHT-TEST SENSORS
- PROVIDE PRODUCTS TO USER COMMUNITY TO DEVELOP APPLICATIONS (OPERATIONAL EXPERIENCE)
  - PRODUCE 1:1,000,000 SCALE PHOTO IMAGES
  - PLOT GEOLOGICAL FEATURES
  - PRODUCE GROSS LAND-USE PLOTS
  - PLOT COASTAL AREAS
  - PLOT SNOW & ICE COVER
  - OBTAIN ANNUAL RECORD OF TEMPORAL CHANGE

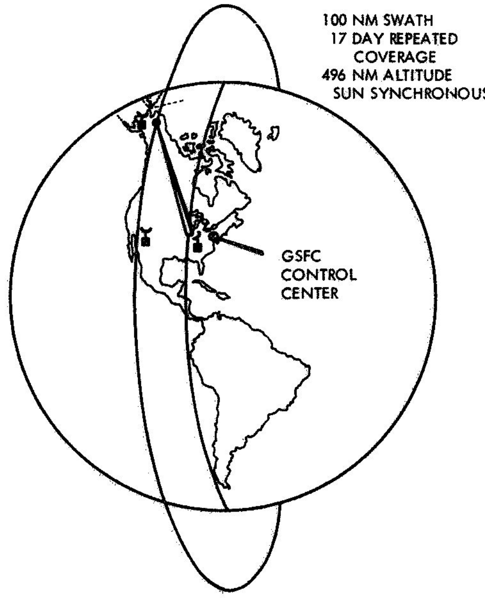

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Figure 14

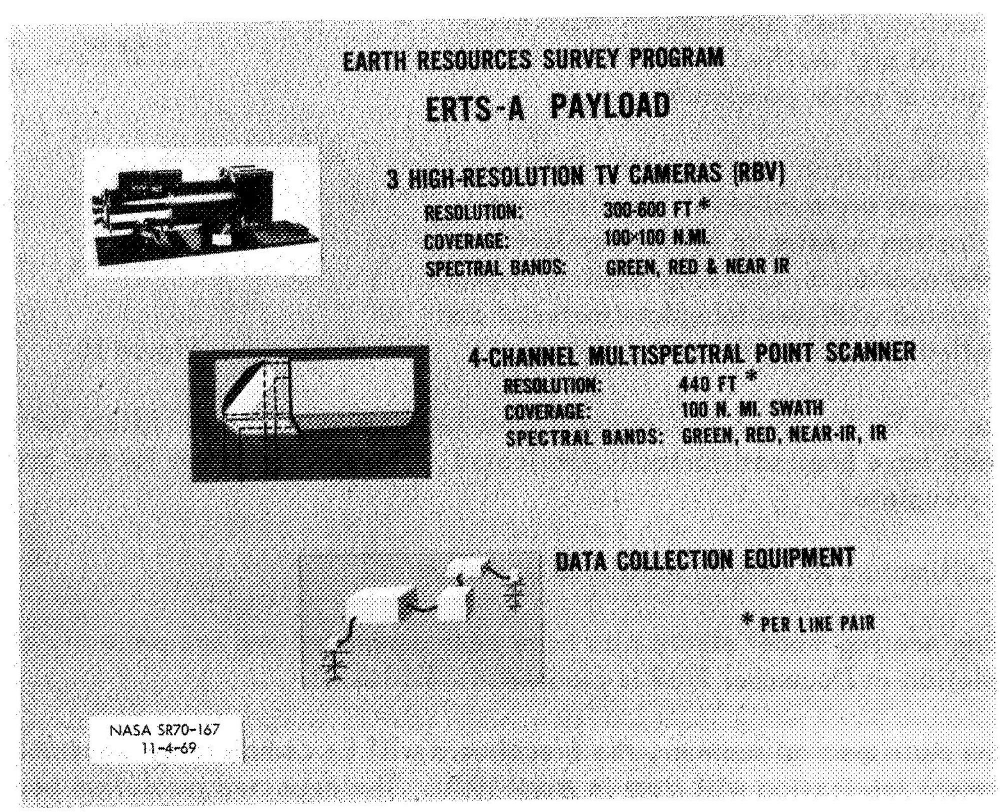

Figure 15

The selection of a high-resolution TV system capable of recording images in three regions of the visible and near IR spectrum is based primarily upon the need to continuously and repeatedly acquire images of the best possible spatial resolution over a large surface area. The provision of a capability for acquiring these images in the three different spectral bands (0.475-0.575, 0.580-0.680, and 0.690-0.830 microns) selected and approved by the user agencies allows for intercomparison of spectral responses which assist in identifying various Earth resources phenomena. The image format (100 X 100 NM) is determined largely by the desire to obtain orthophoto images which are map-like so that correctional modification is not required.

The four-channel scanner (0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 microns) provides an extension in spectral coverage to include important longer IR wavelengths. However, the primary feature which the scanner provides, and which is not readily available from the TV camera system, is the inherent compatibility of the scanner data for automated analysis by digital computers. The feasibility of automatically classifying various Earth resource phenomena has been demonstrated by experimentation with aerial scanner data. The ERTS-A scanner will provide a means to extend the technique of automated information extraction to include data acquired from orbital altitudes on a repetitive and large-scale basis.

The current status of the ERTS-A and B instrumentation is summarized in Figure 16. For the return beam vidicon (RBV) cameras, tube performance measurements have been made and their accuracy and repeatability have been established and verified. The following lists the status of major components.

(1) Sample vidicon tubes meeting ERTS requirements are available. Environmental qualification remains to be accomplished. The photoconductor cracking problem appears to be solved with new faceplate material and controlled photoconductor thickness.

ERTS-A & B

INSTRUMENTATION STATUS

RETURN BEAM VIDICON CAMERAS:

STATUS: BREADBOARD COMPLETE
FLIGHT EQUIPMENT FABRICATION START FEB 1970

PERFORMANCE: (MEASURED SPRING 1969) 4500 ELEMENTS PER SCAN (2 CHANNELS)
3450 ELEMENTS PER SCAN (CHANNEL 3)

MULTISPECTRAL SCANNER:

STATUS: BREADBOARD- COMPLETE DEC 1969
FLIGHT EQUIPMENT FABRICATION START APRIL 1970

PERFORMANCE: 3000 ELEMENTS PER SCAN (4 CHANNELS)

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Figure 16

(2) Lenses for the three RBV cameras have been built. Spectral filters for the red and near IR channels have been satisfactorily fabricated. The spectral filter for the green channel remains to be completed.

(3) Collimators for testing remain to be delivered.

(4) Engineering model electronics have been assembled and are presently undergoing debugging. Completion in December 1969 is planned.

For the multispectral scanner, the breadboard will be complete by December 1969, and flight equipment fabrication will start in April 1970. The expected resolution performance is 3,000 elements per scan for all four channels.

Figure 17 summarizes the present resolution capabilities of the RBV camera system as measured in the laboratory with a high contrast target and as calculated, from the measured data, for typical targets with a standard atmosphere. The factor of two differences between resolution per TV line and per optical line pair should be noted. Thus, the equivalent optical resolution indicated in the chart corresponds to the range 300-550 feet.*

ERTS-A & B

RBV CAMERA — TYPICAL TARGET RESOLVING POWER

	AVERAGE GROUND RESOLUTION (FT/TV LINE)*		
	CH. 1	CH.2	CH.3
MEASURED PERFORMANCE FOR HIGH CONTRAST TARGET IN LABORATORY (TUBE SEB 123)	150	150	165
CALCULATED PERFORMANCE FOR TYPICAL TARGETS WITH STANDARD ATMOSPHERE			
DESERT SAND VS SHADOW	165	160	190
AVERAGE PLANT VS WET LOAM	∞	210	275
AVERAGE PLANT VS DRY LOAM	180	165	275
AVERAGE PLANT VS WATER	275	275	205

*OPTICAL RESOLUTION CORRESPONDS TO TWO TV LINES

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Figure 17

The data collection system referred to in Figure 15 was selected as a candidate for ERTS-A in order to test the feasibility of repetitively collecting and relaying a comprehensive sequence of time-variant data from Earth-based sensors. Typical sensors would measure and transmit to ERTS-A parameters such as stream flow rates, water content of snow, moisture and temperature. ERTS-A would accumulate data on magnetic tape and read it out to ground receiving stations. This _in situ_ "ground-truth" type data would be utilized in conjunction with the RBV and scanner images in conducting user-oriented data utilization experiments.

As a result of competitive procurement, GE and TRW have recently been selected to perform a Phase B/C study to define the ERTS-A and B spacecraft and data management systems. It is expected that each of these aerospace companies will employ, to the most economical and practicable extent, their existing spacecraft designs in meeting the requirements for the ERTS-A and B missions. Figure 18 shows the most probable general appearances of the two spacecraft designs. Upon completion of the Phase B/C study, one spacecraft and data management system will be selected for development.

The principal design and performance characteristics of ERTS-A and B are shown in Figure 19. The one-year lifetime is required in order to repetitively observe time variant phenomena such as are particularly important in the cases of agriculture and hydrology. The near-polar sun-synchronous orbit is required in order to achieve the necessary repetitive continuous coverage

EARTH RESOURCES SURVEY PROGRAM

ERTS A&B SPACECRAFT (PROPOSED)

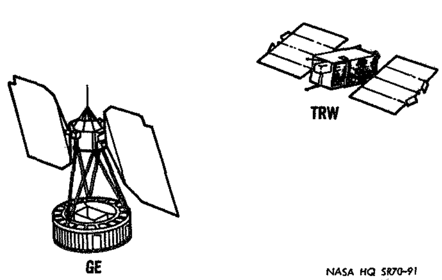

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Figure 18

EARTH RESOURCES SURVEY PROGRAM

KEY DESIGN & PERFORMANCE CHARACTERISTICS OF ERTS A&B

- LIFETIME OBJECTIVE-ONE YEAR
- ORBIT-NEAR-POLAR, SUN-SYNCHRONOUS, CIRCULAR, 496 N.M.
- ATTITUDE CONTROL $<0.7°$
- REPETITIVE COVERAGE EVERY 17 DAYS
- PAYLOAD CAPACITY-350 LBS
- SPACECRAFT WEIGHT ~ 1200 LBS
- MINIMUM POWER-20 MINUTE SENSOR OPERATION PER ORBIT
- WIDEBAND DATA TRANSMISSION-20MHZ, S-BAND
- ON-BOARD DATA RECORDING
- ORBIT ADJUST CAPABILITY

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Figure 19

* The notation of "infinity" in Figure 17 in the column headed Channel I merely indicates that the two target categories cannot be distinguished by the designated RBV camera.

at a constant sun-angle and the orbit height is determined both by the requirement for synchronism and by the need to avoid rapid decay of the orbit. The 0.7 degree attitude control accuracy is adequate for the mission and does not exceed the capability of available subsystem technology. The payload capacity is required to carry the candidate sensors and data collection systems and the spacecraft weight is estimated to be commensurate with structures capable of providing the required payload capacity, power, telemetry, and attitude control systems. The bandwidth requirement for data transmission is established by the characteristics of the signal outputs from the sensors. The provision of a tape recorder on-board the spacecraft will assure full coverage and greater flexibility in choices of areas to be covered. Because of the wide bandwidth and high data rates involved, data transmission and on-board storage will represent the greatest challenges to current technology. An orbit adjustment capability is necessary to achieve and maintain the required orbit for synchronism and continuous coverage during the lifetime of the satellite.

The rate and volume of data expected from ERTS-A & B are large and these data will require great care in handling in order to best preserve the quality of the original sensor responses. Spectral purity, geometric fidelity, and spatial resolution are all extremely important aspects of these data and later successful extraction of information depends greatly upon how well the systems of recording, transmission, reception, re-recording and reproducing are accomplished.

Figure 20 shows the essential components of the data handling and control system and it also indicates the volume of data expected each day. The system consists of the command and data telemetry links, the receiving stations (3), the operations control center (GSFC), the NASA data processing facility (GSFC), and the data services to provide principal users with high quality data master copies. The actual locations for receiving stations have not yet been finalized. The RBV 3-camera television system produces triplets of images and a total of 180 individual frames showing ground scenes 100 X 100 NM in size are to be taken daily. The multispectral scanner takes quadruplets of the scene in the form of a continuous strip-map 100 NM wide. This strip-map is to be reproduced in sections covering ground lengths of 100 NM so that 240 separate images in a 100 X 100 NM format will result each day. The scanner data is also to be reproduced in magnetic tape format and in this case the data would be continuous rather than separated into frames. These taped data from the scanner are to be used in automated information extraction processes.

The Data Processing Facility will provide the necessary inclusion of annotation for geographical location and will precision-process perhaps 5% of the data to remove geometric distortions. Such processing is necessary to facilitate those information extraction processes which require accurate superposition of the several multispectral images of one scene. The data are to be delivered to the users in several formats and degrees of processing depending upon the requirements of the particular investigation. Raw and processed tape, hard copy color, and hard copy black-and-white formats are expected to be useful in the support of the investigations which have been identified for the ERTS-A & B missions. Monitoring the condition of the spacecraft and sensors is closely related to the data handling functions and required real-time data quality assessment in order to properly command the spacecraft.

GROUND DATA HANDLING & CONTROL SYSTEM

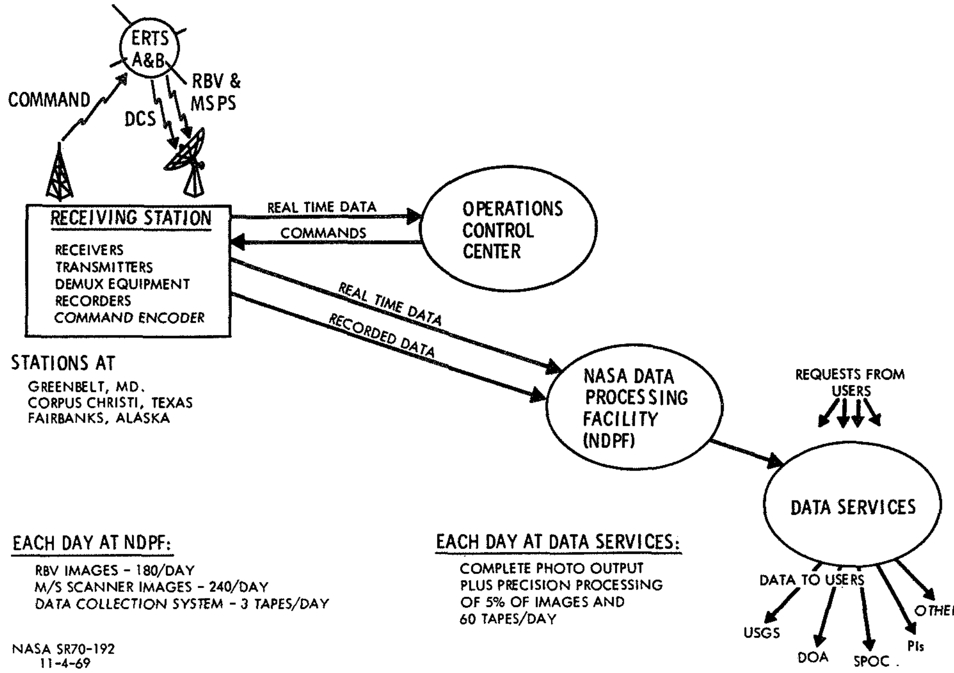

Figure 20

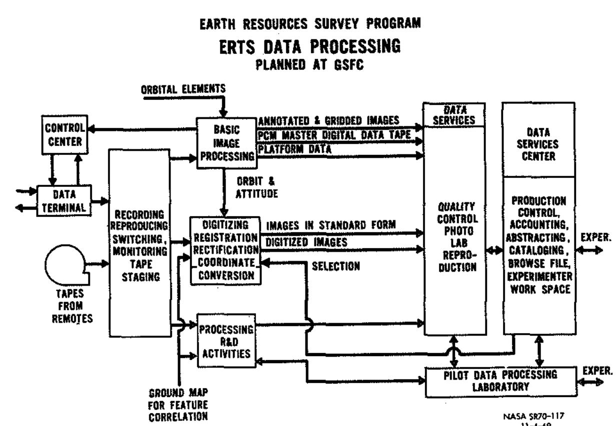

Figure 21

Processing is required in order to provide the experimenters with data of uniformly high quality, in a useful format, and within an acceptable time after acquisition. It is also necessary to provide a means to rapidly recognize the need to apply corrective commands to the satellite and to bring together the orbital element information with the images acquired in order to annotate the data as to geographical location. Figure 21 shows the several inputs and outputs of the data processing system proposed at the NASA Goddard Space Flight Center (GSFC) to handle ERTS-A & B data. The blocks show the principal functions or operations which are now identified as being necessary. The ERTS-A & B Phase B/C study will examine in detail the structure and function of the data processing system and will define a best-fit configuration based upon factors such as input flow rates, user format requirements, cost, quality, and speed of delivery.

The presently large and rapidly increasing amount of data about earth resources relating to a large number of scientific disciplines areas which have already been collected by the ERS Program constitute an extremely valuable and unique source of information. The variety and complexity of this aircraft and spacecraft data, many of which are in the form of color film and in reports which contain color or high-resolution photographs, preclude low-cost mass reproduction without drastic loss of information content. In order to provide access to these data for study by investigators and other interested parties, an ERS research data facility (Figure 22) was recently established at the NASA Manned Spacecraft Center (MSC) at Houston, Texas. A comprehensive cataloging and retrieval system enables the user to locate data, and provision is made for viewing imagery so that specific portions can be selected for further study as required to support the experimenters' research.

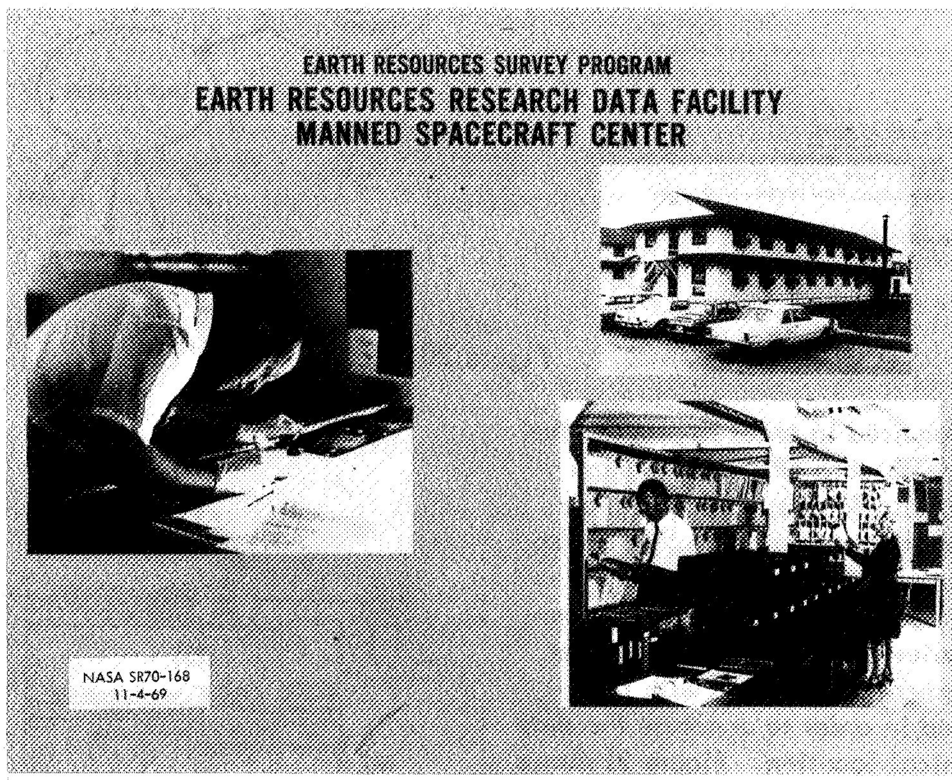

Figure 22

Figure 23 summarizes the growth in the amount of data and indicates the use being made of the Earth Resources Research Data Facility. The graph showing the rate of accumulation of documents before and since the official establishment of the facility in July 1969 reflects the scope of research activities conducted by the ERS Aircraft Program. It should be pointed out that the quality and substance of these reports have also markedly increased as have the quality, variety, and amount of acquired data. The breakdown of numbers and

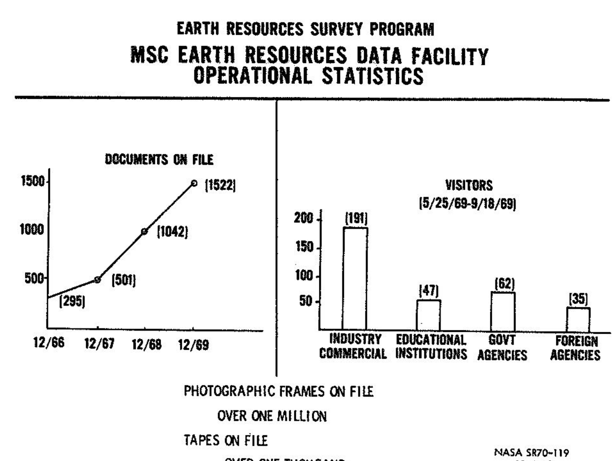

Figure 23

affiliations of visitors to the facility is indicative of the high degree of interest which these kinds of data create. The relatively high proportion of visitors from the industrial and commercial communities indicates strongly that these kinds of data have potential for practical applications. The fact that over one million photographic frames are currently on file, indicates the scope of the evolving ERS data handling problem particularly in view of the forthcoming ERTS-A & B data.

As part of our ERTS series, it is proposed to utilize a film recovery satellite to provide an early high-resolution record of the earth's surface in a number of spectral bands with metric accuracy. These film recovery satellites would be functioning during the service life of ERTS-A & B. The data to be obtained from these missions will contribute to and make possible the following objectives (Figure 24): (l) provide a high-resolution record of the contiguous United States, Alaska, Hawaii, and adjacent water areas as a correlation base for the lower-resolution electronic return data of ERTS-A & B; (2) provide a comprehensive inventory of natural resources as a base for future higher-resolution telemetry-type earth resources satellites; and (3) provide an economic means of preparing and updating mapping information for orthophoto maps, thematic maps, and cartography in general.

EARTH RESOURCES SURVEY PROGRAM

ERTS C&D FILM RETURN

– PROPOSED OBJECTIVES –

PROVIDE EARLY HIGH-QUALITY RECORD OF EARTH'S FEATURES

- FOR REFERENCE IN ANALYSIS OF ERTS ELECTRONIC RETURN DATA
- AS BASE FOR EARTH CHANGES OBSERVED ON LATER FLIGHTS
- MAPPING -EARLY CAPABILITY

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Figure 24

The payload module for ERTS-C & D would, conceptually, consist of a camera section and a film recovery vehicle as shown in Figure 25. Included in the camera section are metric cameras of approximately the same resolving power as the Apollo cameras but with metric fidelity. The film recovery vehicle contains the exposed film from all cameras, and provides reentry and recovery capability when separated from the rest of the spacecraft at the end of the orbital phase of the mission. The illustration shown in Figure 25 is based on one contractor's concept presented about two years ago. This and similar work has just been reviewed by MSC in a Phase A study. The proposed concept is now ready for Phase B/C so that launches concurrent with ERTS-A & B could be achieved. The proposed recovery sequence is illustrated in Figure 26 (over). Initiation of the recovery sequence will be commanded from one of the ground stations prior to the last (recovery) orbit. The operational phase of the recovery could be executed in cooperation with the Air Force.

EARTH RESOURCES SURVEY PROGRAM

ERTS C&D FILM RECOVERY CONCEPT

INBOARD PROFILE

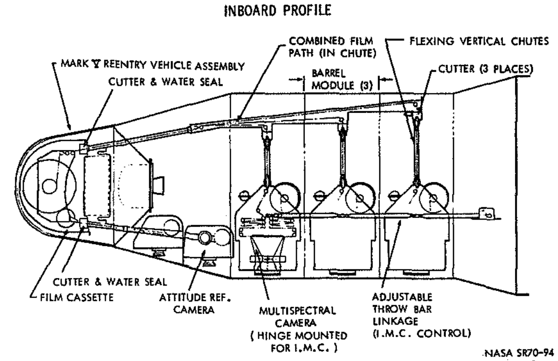

Figure 25

Figure 26

While it is anticipated that ERTS-A & B will gather data on coastal processes and possibly some other oceanographic activities, these first two ERS dedicated electronic return satellites will give priority to land-oriented objectives. In order to more fully satisfy the important needs of the oceanographic community at an early date as well as to carry out the mandate in spacecraft oceanography given to NASA by the Marine Council, it is proposed to undertake ERTS-E & F which will have ocean surveys as their highest priority objective. In order to achieve early implementation, ERTS-E & F would probably employ spacecraft and subsystems similar to ERTS-A & B but with sensors and orbits optimized for ocean surveys. This concept is illustrated in Figure 27.

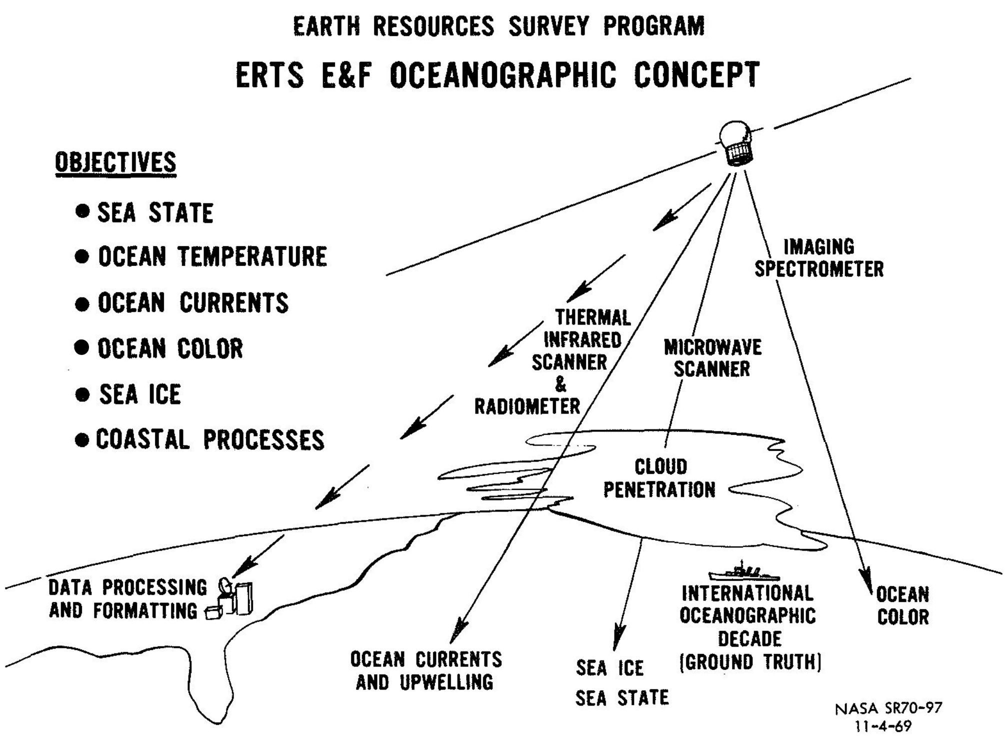

Figure 27

It is proposed that ERTS-E & F have as their mission objectives the acquisition of information on sea state (ocean waves), ocean surface temperature, ocean color, ocean currents, sea ice, and coastal processes. This information will be made available to user agencies and other groups for subsequent analysis and applications.

In the ERTS-E & F concept, the remote sensor payload would consist of, for example, a thermal infrared scanner and radiometer, a passive microwave scanner, and an imaging spectrometer. Measurements of ocean surface temperatures would be made by the infrared remote sensors. From measurements of the horizontal temperature gradients, it would be possible to delineate major ocean current tracks and their variations both in time and location, as well as regions of upwelling water (which are known to bring nutrients up to the surface layer for the plankton which are the main source of food for schooling fish). Information on sea state conditions would be obtained by the microwave scanner. The operating frequency of the scanner would be selected to allow the acquisition of signals through cloud cover as well as during clear conditions. Information on ocean color and coastal processes would be obtained by the imaging spectrometer.

Because the ocean is a dynamic medium of great extent, special attention will be necessary to obtain "ground-truth" information for use in correlating the remote sensor data with the physical parameters being observed. Advantage will be taken of oceanographic research ships of opportunity to gain this information. It is also expected that an International Decade of Ocean Exploration will be underway during the conduct of the ERTS-E & F missions. If this should be the case, plans will be made in advance for appropriate coordination. Because of the global coverage of the oceans and the increasing interest of many nations in the oceans, it is anticipated that many foreign scientists will be collaborating in the analysis and applications of the data. An advanced study of concepts and mission requirements for ERTS-E & F will be undertaken during the current fiscal year (FY-70).

There is a need to supplement the larger, relatively complicated multi-sensor satellites of the ERTS series with a capability for early and rapid space flight testing of sensors and subsystems. The proposed mechanism for accomplishing this is the Small Applications Technology Satellite (SATS) illustrated in Figure 28. In the SATS program it is proposed to utilize relatively small Scout class spacecraft to conduct a coordinated program of experimental research and technology development over the entire Space Applications area. Having small spacecraft with basically single purpose experiments will considerably simplify the mission. The orbits of the SATS will be optimized for the particular experiments that are carried, and operational requirements will only be considered on a noninterference basis with the experimental requirements. Because of the simplicity of the spacecraft and the use of the all-solids Scout launch vehicle, the turn-around time at the launch pad should be on the order of a few days. It is anticipated that some missions may require durations up to about one year. The SATS missions will serve in the accomplishment of (1) testing critical subsystem improvements; (2) testing of advanced sensors; and (3) providing early flight tests for experiments. There are a number of experiments and experiment proposals presently available for implementation on

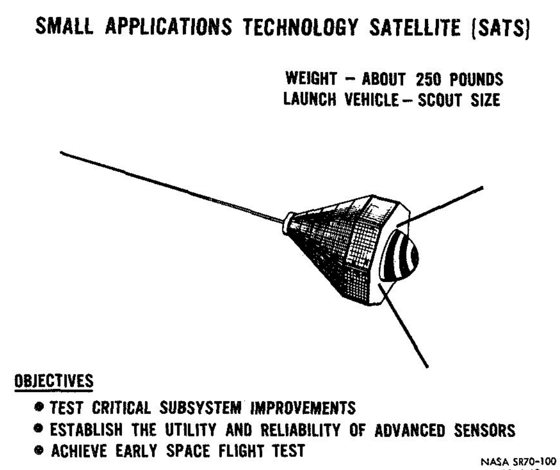

Figure 28

EARTH RESOURCES SURVEY PROGRAM
SMALL APPLICATIONS TECHNOLOGY SATELLITE (SATS)
– CANDIDATE EXPERIMENTS –

- DRAG-FREE SATELLITE TECHNOLOGY
- MICROWAVE RADIOMETRY
- WIDE RANGE IMAGE SPECTROMETER
- RADIOMETRIC VERTICAL SENSOR
- COMPOSITE RADIOMETER-SCATTEROMETER
- VISIBLE RADIATION POLARIZATION MEASUREMENT
- NANO-G ACCELEROMETER
- MILLIMETER WAVE PROPAGATION
- DATA COLLECTION SATELLITE TECHNOLOGY
- SATELLITE ALTIMETER TECHNOLOGY

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Figure 29

SATS. A listing for some typical candidate experiments is shown in Figure 29. It may be noted that, in addition to remote sensing payloads, data collection and Earth physics-type payloads (drag-free satellite and satellite-altimeter) are included. A Phase A study is planned on SATS during the current fiscal year (FY 1970).

The Earth observations program has employed both manned and unmanned spacecraft for acquiring data. As mentioned previously, both the Nimbus and ATS spacecraft have provided imagery and data which has been useful in Earth observations; certainly the early photography from manned missions (Gemini and Apollo) has been a tremendous catalyst in focusing attention on the potential of remote sensing from space platforms. The principal objectives of manned mission experiments in the current program are to determine the role of man, to develop instrumentation for Earth observation, and to provide an earlier source of research data for analysis (Figure 30).

EARTH RESOURCES SURVEY PROGRAM
MANNED MISSION EXPERIMENTS

OBJECTIVES

- TO DETERMINE ROLE OF MAN
- TO DEVELOP INSTRUMENTATION
- TO PROVIDE EARLIER SOURCE OF R&D DATA

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Figure 30

The various platforms and missions in the manned program as they relate to Earth resources are illustrated in Figure 31. The early hand-held color photography from Mercury, Gemini and Apollo provided imagery which a number of scientists in universities, industry and government found of great professional interest. Geologists, in particular, found that these large-area, small scale images revealed features which had never before been identified by conventional aircraft or ground means. This enthusiasm and evident promise led to the design of the first controlled multispectral photography experiment (SO65) carried out during March 1969 from Apollo 9. This experiment employed four Hasselblad cameras rigidly mounted to a hatch window of the Apollo Command Module. Three of the four cameras used black-and-white film with filters to match the proposed bands (green, red, near-IR) for the ERTS TV cameras. The fourth camera contained color infrared film. Coverage of a number of user test sites during the mission confirmed the choice of bands for the ERTS TV cameras as well as providing a considerable quantity of data for user analysis. It is also possible to simulate ERTS data to facilitate earlier development and checkout of ERTS ground data handling systems.

An example of Apollo 9 SO65 multispectral imagery is shown in Figure 32, the now-familiar Salton Sea - Imperial Valley area. The images shown are in color IR, and green, red and near-IR bands, approximating the proposed ERTS bands. This and similar data has been used to verify the capability of the green band for water penetration, the red and near-IR band for crop and features identification and the near-IR band for plant stress detection and identification of surface water.

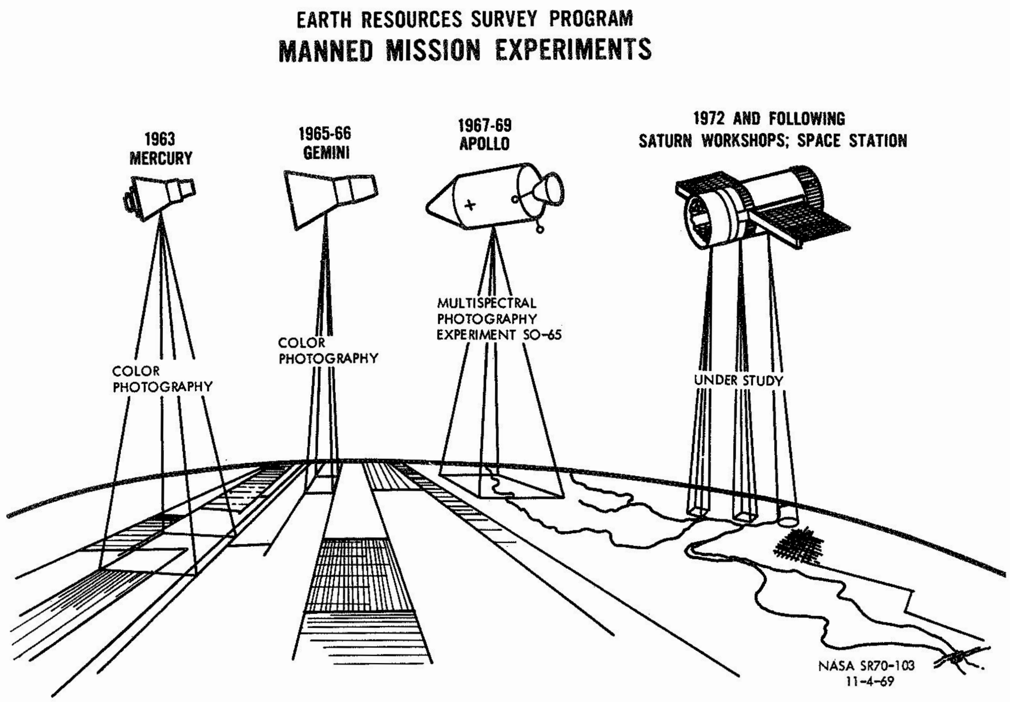

Figure 31

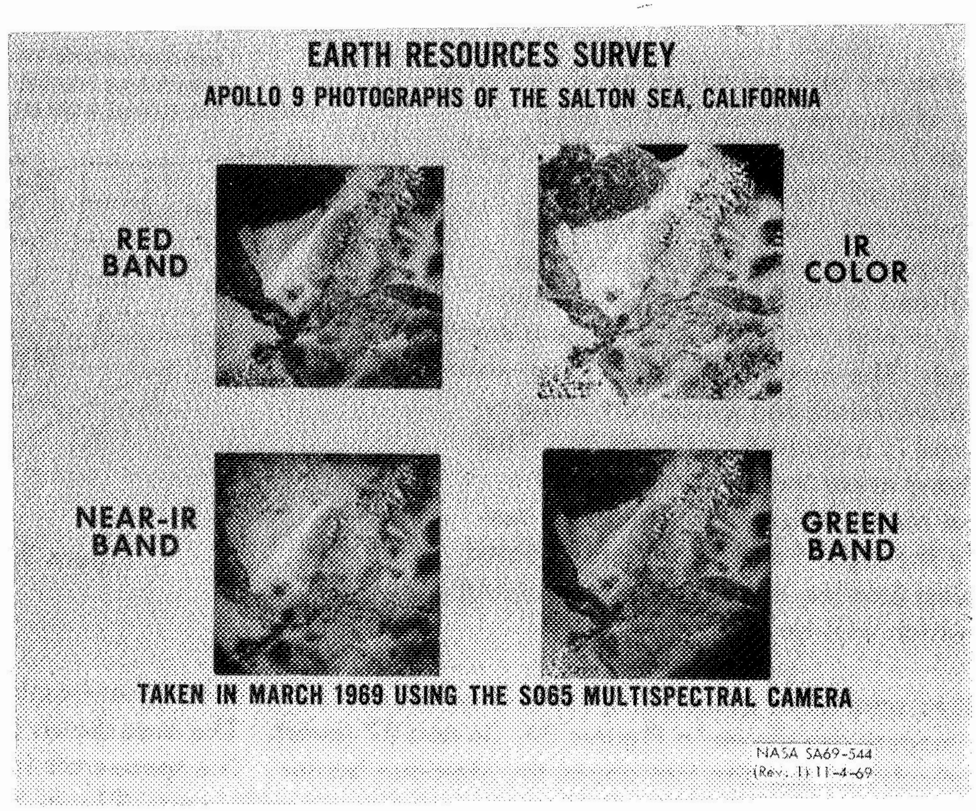

Figure 32

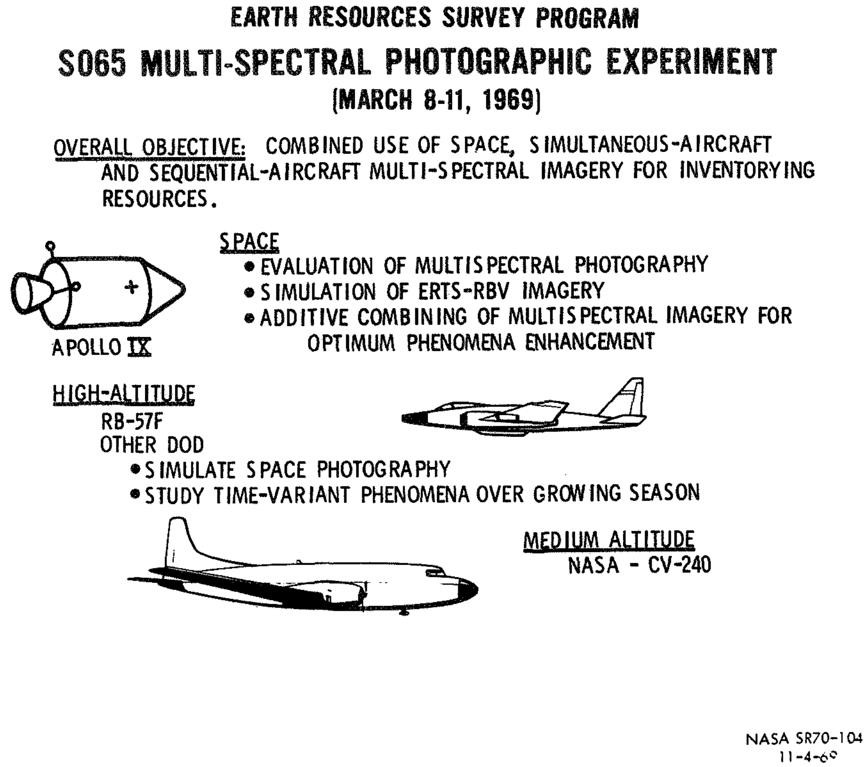

Figure 33

In addition to the primary objective of verifying the choice of spectral bands for the ERTS TV cameras, an initial attempt was made in SO65 to evaluate the utility of simultaneous spacecraft-aircraft imagery and sequential aircraft imagery for inventorying resources. This is outlined in Figure 33 where the concurrent use of high and medium altitude aircraft is indicated. The areas of the U.S. over which simultaneous aircraft and spacecraft imagery was obtained is indicated in Figure 34. The two left-hand areas include the Imperial Valley and Mesa, Arizona, agricultural test sites while the right-hand areas were covered by the Forest Service in a timber inventorying example which will be discussed shortly.

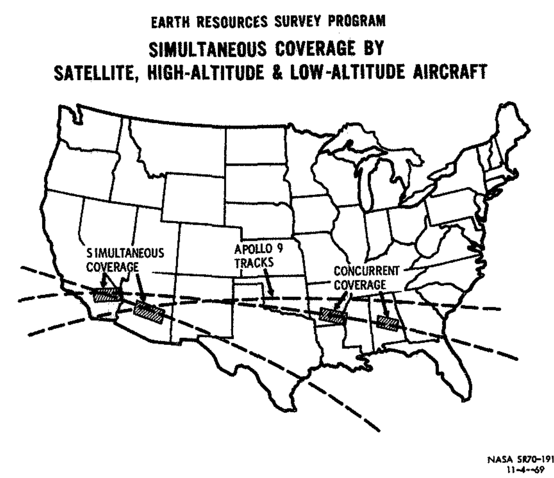

Figure 34

Comparative samples of spacecraft, lower-resolution aircraft and higher-resolution aircraft, color-IR imagery are shown in Figures 35, 36 and 37 (over). The area shown is the Imperial Valley agricultural test site just above the Mexican border. The spacecraft image (Figure 35) is at a scale of 1:2,600,000, the lower-resolution aircraft image (Figure 36) is at a scale of 1:940,000 and the higher-resolution aircraft image (Figure 37) is at a scale of

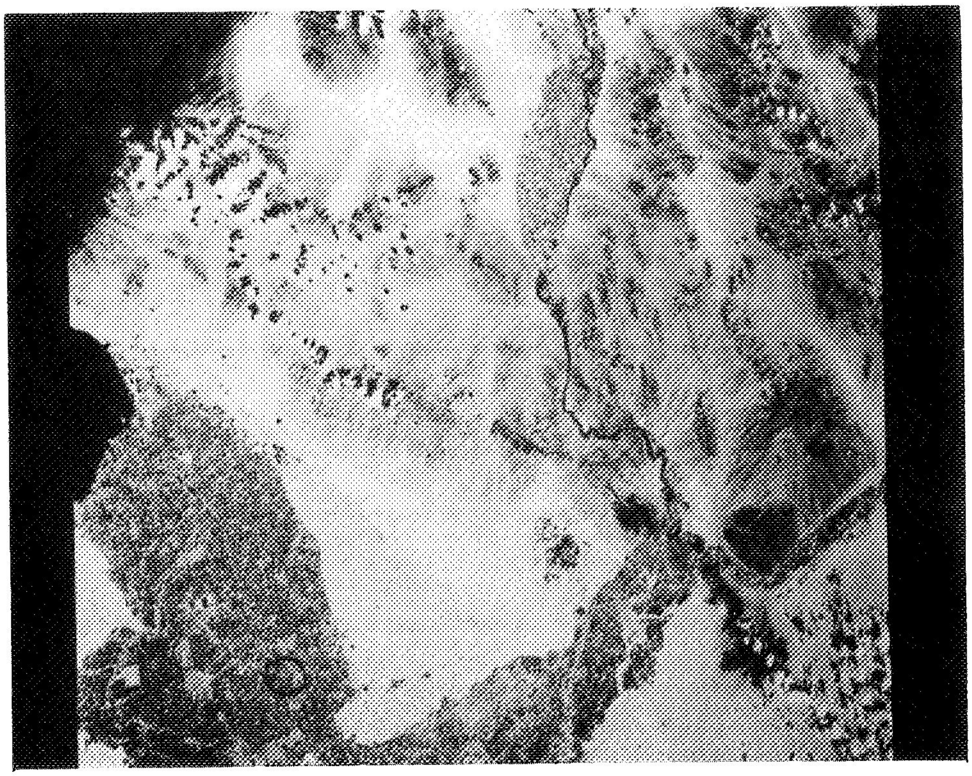

Figure 35

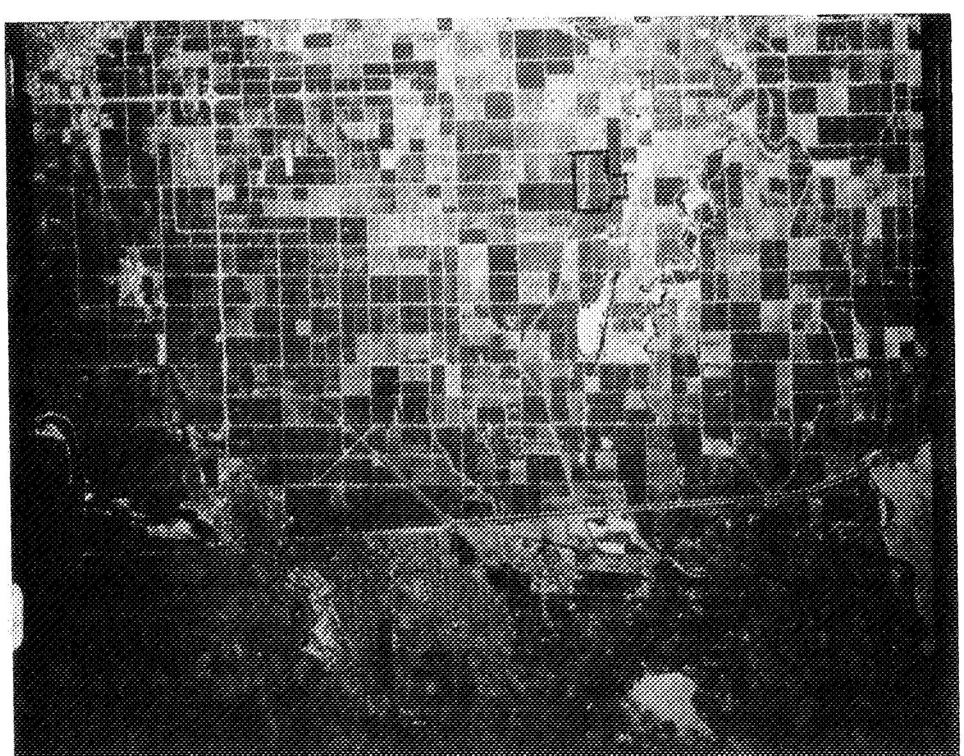

Figure 36

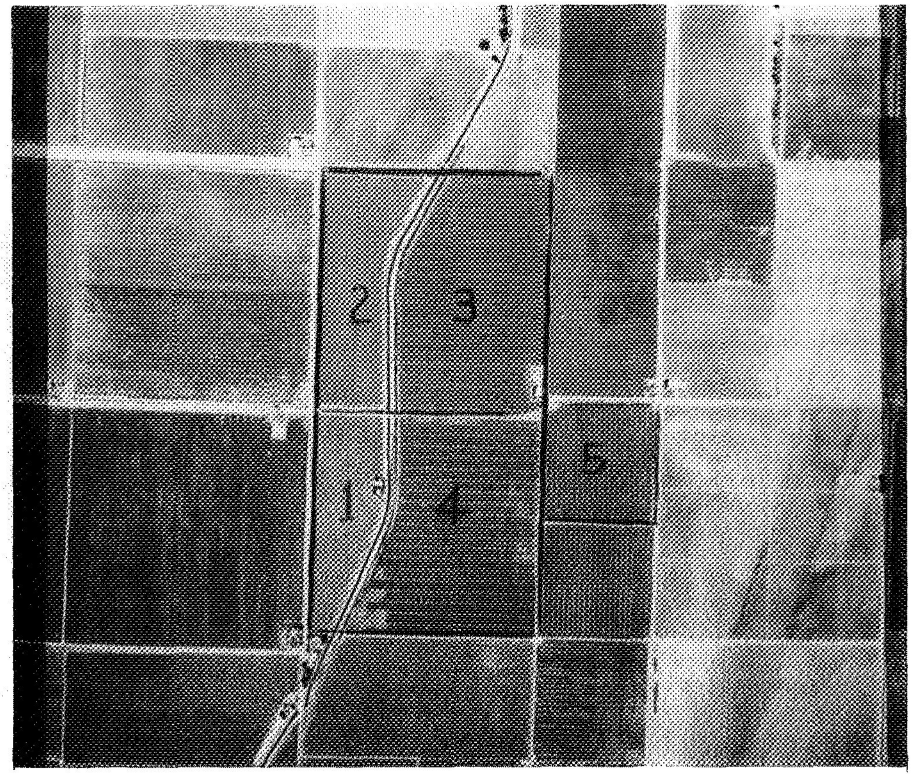

Figure 37

1:68,000. It may be of interest to note the clear demarcation of the Mexico-U.S. border due to differences in land-use practices. The twin cities of Mexicali, Mexico, and Calexico, California, are clearly seen in the Figure 36.

The test fields, as seen in Figure 37, are sugar beets (fields I and 2) and alfalfa (fields 3, 4 and 5). It is of interest to note that, while the cutlivation patterns first become evident in the I:68,000 image (Figure 37), the tonal signatures are well-preserved in the small-scale spacecraft imagery. These types of tonal signatures, when combined with sequential coverage, have established the feasibility of constructing crop calendars which, in turn can be used for identification, vigor, and yield estimation.

The time variability of crop signatures is illustrated in Figure 38 which shows three color IR images of the same agricultural test site in Mesa, Arizona, taken at one-month intervals using a high-altitude aircraft. The first image (on the left) was taken concurrently with SO65 (Apollo 9). A typical wheat field and a typical sugar beet field are indicated on the images and the tonal progression can be followed from left to right during the growing season. The wheat field shows a very distinctive change in tone in the May image due to harvesting having taken place. The sugar beet field shows some tonal change as the growing season progresses. In addition, it can readily be noted that there are significant overall tonal variations in the three images probably due to film, exposure, and processing differences. This illustrates some of the difficulties of dependence on photographic film techniques.

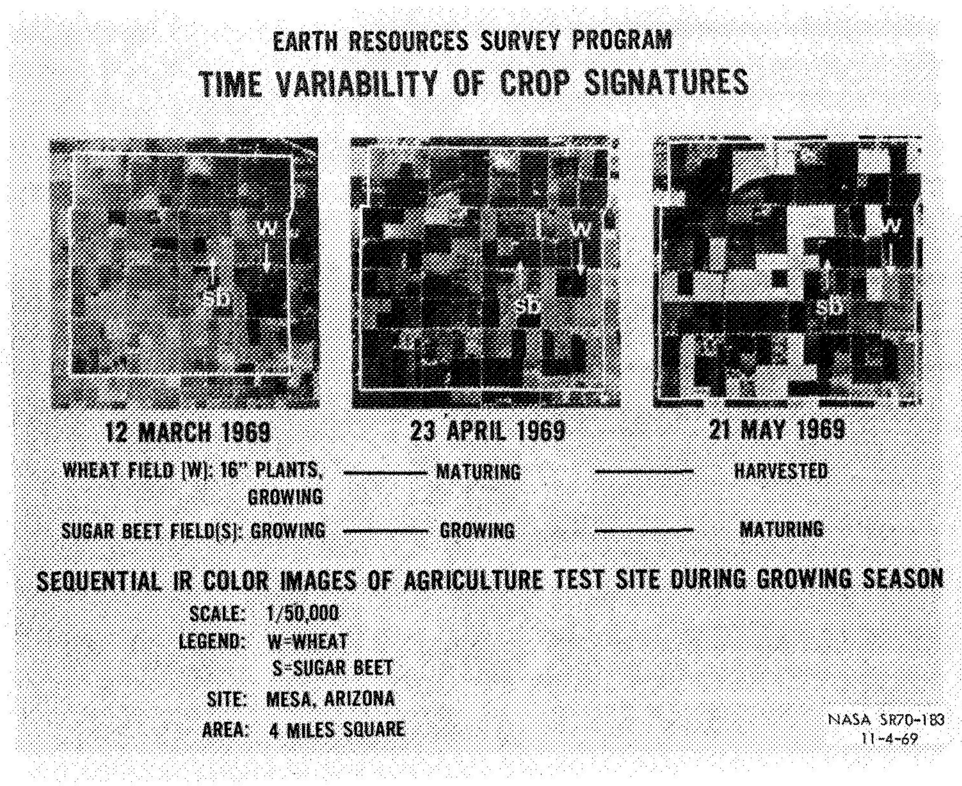

Figure 38

IV. SUPPORTING RESEARCH AND TECHNOLOGY (SR&T)

The third major portion of the ERS program is referred to as supporting research and technology. This may be divided roughly into three general categories: (1) sensor-signature research, (2) instrumentation research and development, and (3) advanced studies.

1. Sensor-Signature Research - In the earth resources SR&T program, we have been pressing for establishment of quantitative relationships in the analysis of remote sensing. Some notable work has recently been demonstrated by the Forest Service in the application of Apollo 9 (SO65) spacecraft imagery, together with concurrent aircraft and ground data, to the practical operational problem of timber inventorying. The principal area inventoried consisted of 5,000,000 acres of the Mississippi Valley, in the states of Louisiana, Mississippi and Arkansas, as shown in the Apollo 9 color photograph in Figure 39 (over). The mathematical formulation is based on a multi-stage sampling analysis technique indicated in Figure 40 (over). The calculated timber volume (V) is determined by five stages of sampling and calculation with the first stage being dependent directly on space imagery, the three intermediate stages being dependent on aircraft coverage, and the last stage being dependent on the detailed but limited tree volume measurements on the ground.

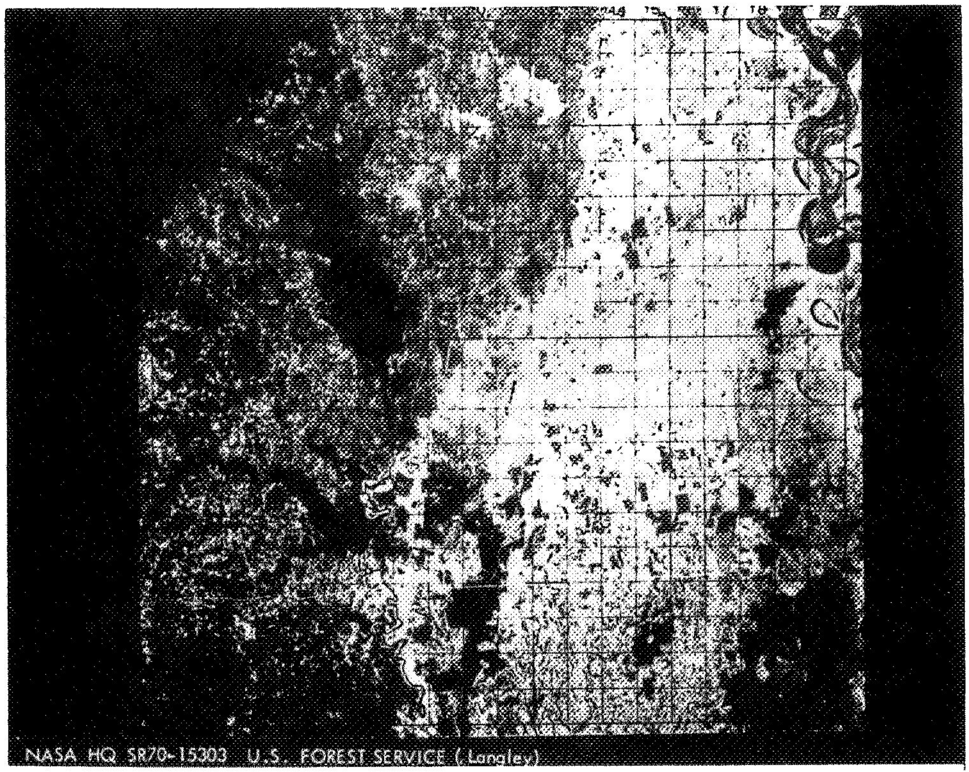

Figure 39

Very briefly, the procedure is as follows: Each frame of the space imagery (Figure 39) is divided into 4 x 4 mile squares, and estimates of the percentage of timber in each square are made. More detailed estimates from aerial photography at scales of 1:60,000, 1:12,000 and 1:2,000 are made on a probability basis. The sample areas of 1:2,000 scale are divided into four quadrants and the actual timber content of each of these samples is estimated and measured on the ground by a further sampling technique. Without delving into the mathematical details any further, the procedure can be viewed as bridging, by statistical techniques, the gap between the broad coverage, but more modest resolution of space imagery and the precise, but very limited, sample measurements that can be done economically on the ground.

EARTH RESOURCES SURVEY PROGRAM
MATHEMATICAL FORMULATION
OF
MULTI-STAGE SAMPLING ANALYSIS TECHNIQUE
FOR TIMBER INVENTORY

$$V = \underbrace{\frac{1}{m}\sum^{m}\frac{1}{P_i n_i}}_{\text{1st STAGE}} \cdot \underbrace{\sum^{n_i}\frac{1}{P_j}}_{\text{2nd STAGE}} \cdot \underbrace{\frac{A_j}{a_c}}_{\text{3rd STAGE}} \cdot \underbrace{\frac{1}{P_p t_p}}_{\text{4th STAGE}} \cdot \underbrace{\sum^{t_p}\frac{V_K}{P_K}}_{\text{5th STAGE}}$$

VOLUME ON PLOT
VOLUME IN CLUSTER
VOLUME IN STRIP
VOLUME ON 4 x 4 MILE SQUARE
TREE VOLUME ON ENTIRE SPACE PHOTO

— SPACE — —AIRCRAFT— —GROUND—

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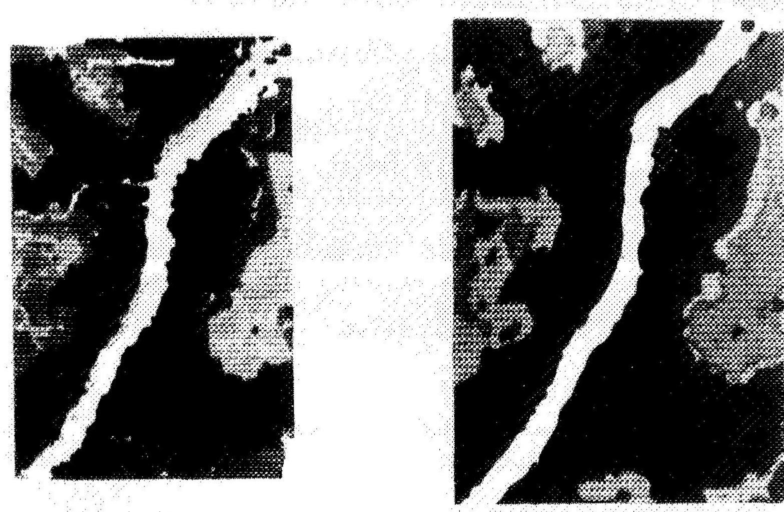
Figure 40

The calculations carried out in this pilot inventory of 5,000,000 acres have demonstrated a reduction in expected error in the timber volume estimate from 31% to 13% due directly to the utilization of the space imagery. This represents an 58% reduction in error which can be reflected directly in aircraft-hours and man-hours required to complete the inventory with a fixed expected error. Thus, with the benefit of the information obtained from the Apollo 9 photography, it would have been possible to reduce the required man-hours by a factor of approximately 6:1 while maintaining the same accuracy in the estimate of timber volume. These 6:1 savings apply directly to the aircraft flight hours, the maintenance crews, the photointerpreters who evaluate the large-scale aerial photos, and the field crews who locate the plots on the ground and measure the sample trees.

This application example demonstrates the potential for practical savings in operational inventorying problems through exploiting the complementary nature of space and aerial imagery in a statistical sampling approach. The technique should be applicable to other Earth resources inventorying problems.

Significant progress is also being made in the area of automatic classification of Earth features using digitized data as is obtained from a multispectral scanner. The original work done at Purdue University was focused on crop identification and considerable success has been achieved and previously reported on. More recently, attempts have been underway to extend these identification techniques to other types of Earth features. Some promising results in automatic soil classification as illustrated in Figure 41. The area shown is an agricultural test site in Tippicanoe County, Indiana. Both digitized images were processed

AUTOMATIC SOILS MAPPING



Computer printout of seven soil categories based on Spectral Properties. Note correlation between maps of Soil Colors and Organic Matter.

Figure 41

from line scan information obtained with the Michigan multispectral scanner. The left-hand image represents the classification of soils by standard color indices. The right-hand image shows the same test area classified according to organic matter content. In both cases, the automatic classifications correlated over 90% correct when compared to ground-truth measurements.

The Purdue automatic digital classification techniques are being extended into the geological area. A promising example of automatic terrain classification is shown in Figure 42. Ten terrain classes have been identified in a test area within Yellowstone National Park. Three classification results are shown. In the top one, an optimum set of four spectral bands were used; in the middle band, the three proposed ERTS bands were used; and, in the bottom one, a thermal IR band was substituted for the ERTS green band. It is significant to note that: (1) all three criteria produced relatively high levels of correlation with ground truth (81-86%) and (2) that the ERTS bands produced very nearly the same accuracy (82%) as the four optimum bands (86%). This indicates considerable promise for automatic terrain classification from ERTS data.

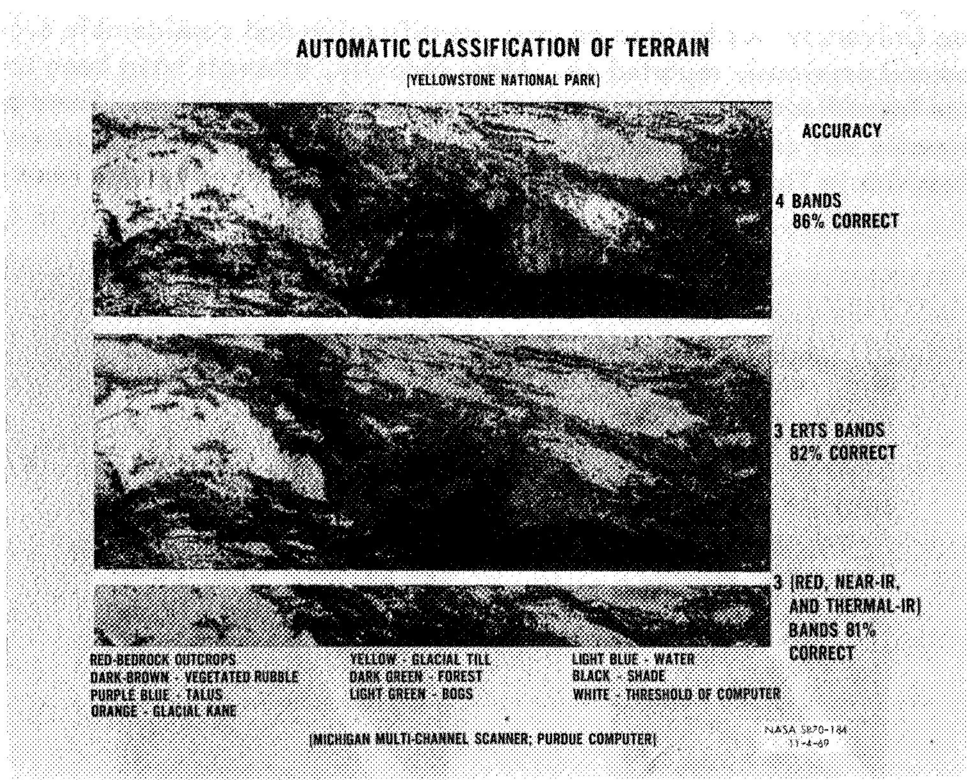


Figure 42

Let us now take a look at the oceanographic area and particularly some implications for what we may expect in this application from ERTS-A & B data. A significant Apollo 9 handheld color photograph of Cape Lookout, North Carolina, is shown in Figure 43. This image has been color separated into two black-and-white images as shown in Figure 44 and Figure 45 (over). Figure 44 now represents what would be seen by the ERTS-red band and Figure 45 represents what would be seen by the ERTS-green band. The red band shows only surface and

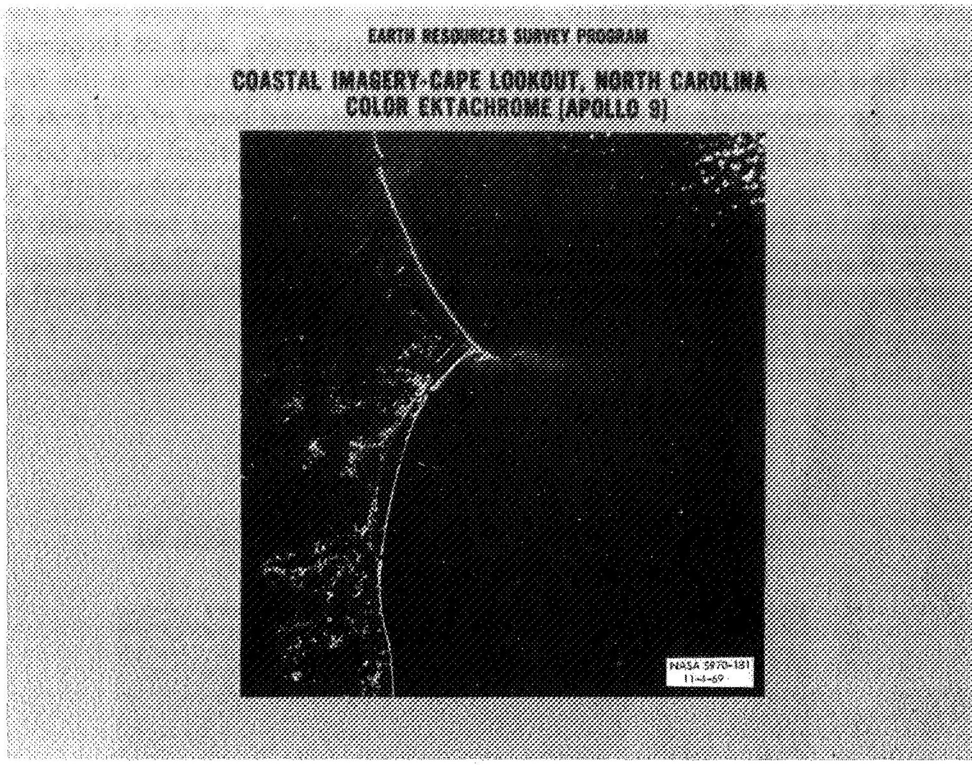


Figure 43

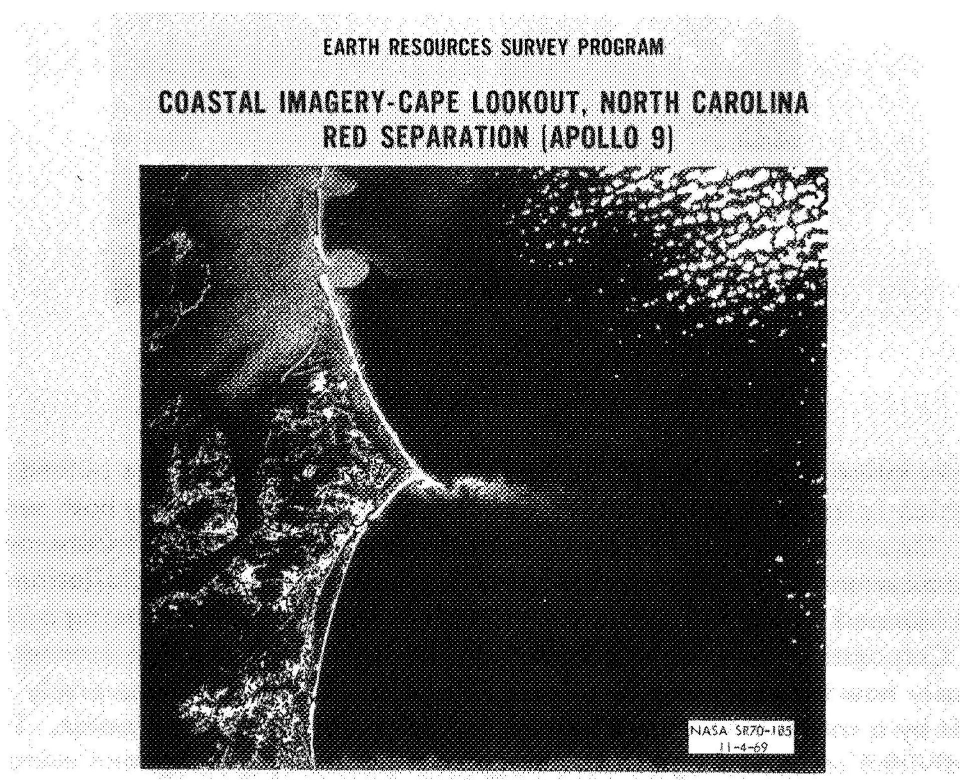


Figure 44

shallow water features such as sediment, shoals, etc., while the green band penetrates to greater depths. Thus one may conclude that coastal processes, such as large-scale sedimentation flow patterns, together with the smaller-scale behavior in the inlet areas, will potentially be observable in the green and, perhaps, red band of ERTS-A & B. Actual depths of water and effective distribution of sediment in the vertical water column are being quantified by means of experiments such as the Ben Franklin submersible measurements recently conducted in the Gulf Stream. The experiments involved test panels of known reflective characteristics mounted on the top of the submersible. These test panels carried were detectable down to depths of 25 meters. The Ben Franklin approach will be expanded to include many water types with simultaneous spectrometric measurements of subsurface downwelling light, water content and multispectral photography of subsurface targets.

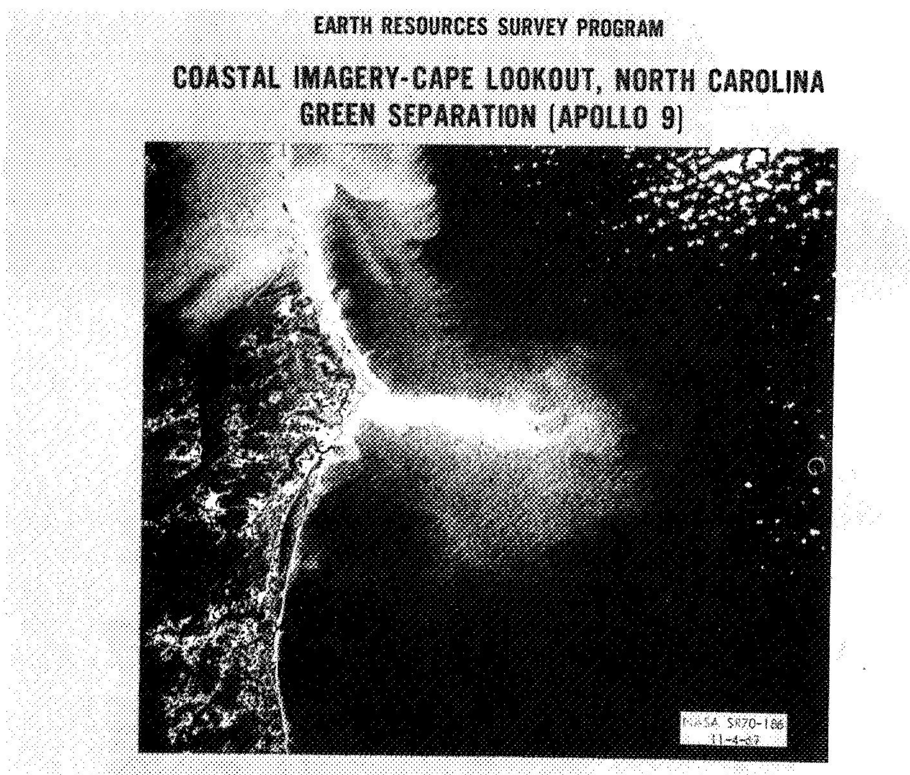


Figure 45

2. Instrumentation Research and Development - Let us now turn to the second general area of SR&T which is instrumentation research and development, including both sensors and data handling. One of the most significant recent developments in aircraft instrumentation is the current procurement of a 24-channel research scanner for eventual installation in the C-130B aircraft at Manned Spacecraft Center. A sketch of this scanner now being built for NASA by Bendix Corporation is shown in Figure 46. The line-drawing of the scanner indicates schematically how the apparatus functions. The scene is scanned transversely to the path of the aircraft by a rotating 45-degree scan mirror driven by an electric motor. The collected energy is divided up according to wave length, dispersed by gratings and measured by appropriate detectors (e.g., photomultiplier tubes, silicon diodes and cooled detectors). During each rotation of the scan mirror, the system observes a series of calibrating sources

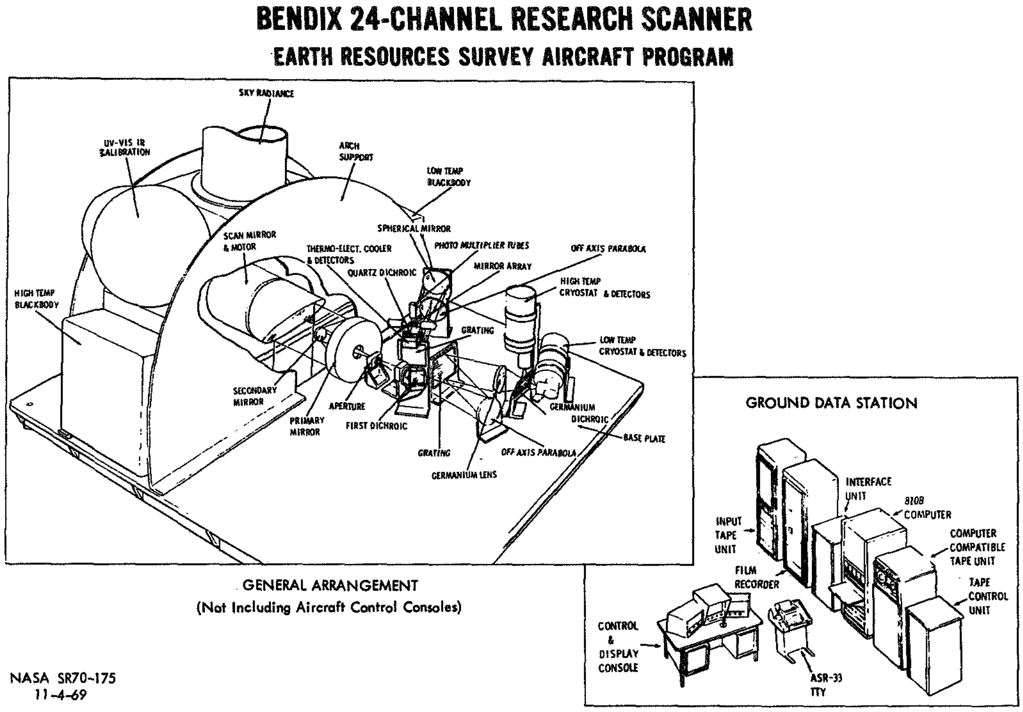


Figure 46

appropriate to the various bands. In addition to the scanner itself, airborne control consoles will be provided as will the ground data station illustrated in the figure. The total weight of airborne equipment will be about 2,600 pounds.

Our experimentation and studies over the past several years indicate that the variances in spectral response of many Earth resource phenomena provide a means of remote mapping and identification. In order for the analysis to be effective, however, one must be able to simultaneously observe the response of the object in the several desired spectral regions. If taken with several separate instruments, the intercomparisons of response become inaccurate because of extreme difficulties in achieving registration and because of instrument response differences. If the observations are made through a single aperture by one instrument such as the scanner depicted in Figure 46, there is inherent registration and the relative instrumental error is much easier to control. Equally important is that the outputs from a multichannel scanner can conveniently be stored on magnetic tape, hence assuring that the spatial relationships as well as the radiometic response of each element of the scene are preserved and can be read-out as required. Of considerable importance is that the recorded data is compatible with automated processing methods by digital computers so that the complex operations involved in analysis and interpretation can be rapidly and accurately completed.

The 24-channel scanner is designed to be a research instrument which should provide a wide range of information about the nature of the "signatures" which provide the means to identify Earth resources phenomena. It is not expected that as many as 24 channels of data will be required to achieve a satisfactory probability of correct classification of any individual Earth resources phenomena. In any single case, perhaps three to seven channels will prove adequate. However, different classes of objects may require a different set of channels for optimum classification accuracy and there is great practical value in knowing which spectral bands are most suitable for the identification of a variety of economically significant phenomena. The selection of optimum numbers of channels and wavelengths needed for data acquisition from space by multi-channel scanners is highly significant in terms of costs and complexity of flight equipment, on-board storage, down-link transmission, and on-the-ground data management.

Figure 47 provides an overall view of the FY 1969 and FY 1970 levels of effort for research and for procurement of instruments for Earth resource remote sensing and data management. The differences in dollar scales for the research and the procurement areas should be noted when examining the figure. The funding for instrument research (top of Figure 47) is categorized according to the spectral region in which the device operates. The generic types of instruments include cameras, radiometers, spectrometers, and radars. Both imaging and non-imaging systems are being investigated as well as are the related instrumentation for data reduction and information extraction. The instrument research category generally carries the work through the feasibility study phase and usually includes the demonstration of performance by means of laboratory or field test models which in turn serve to define versions of the device which would be suitable for aerial or space flight development and experimentation. The instrument procurement category (bottom of Figure 47) includes the funding levels aimed at the building of hardware to meet the specifications required for use in the aircraft program and in the ERTS-A & B spacecraft program. The very significant increases in spacecraft instrument procurement in FY 1970 is, of course, a reflection of the ERTS-A & B program implementation.

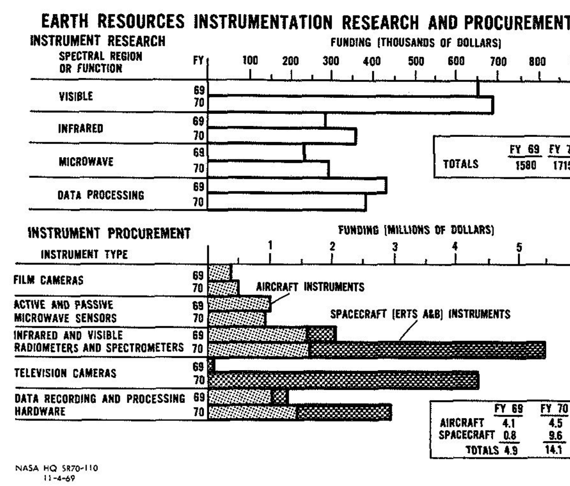


Figure 47

3. <u>Advanced Studies</u> - In order to effectively guide research efforts and allocate funding in the Earth Resources Survey Program, it is necessary to develop some understanding of what the total Earth resources survey system may be, both in the operational prototype phase and subsequent operational phase. This type of understanding is being acquired by means of our advanced study program. The evolution of this study program is illustrated in Figure 48. Initially, the effort was responsive largely to program justification needs and was focused on cost-benefit analyses in a future operational context. In order to proceed, it was necessary to conceptualize examples of total future operational systems, before any economic analysis could be done. Aside from the questions of cost and benefits per se, the

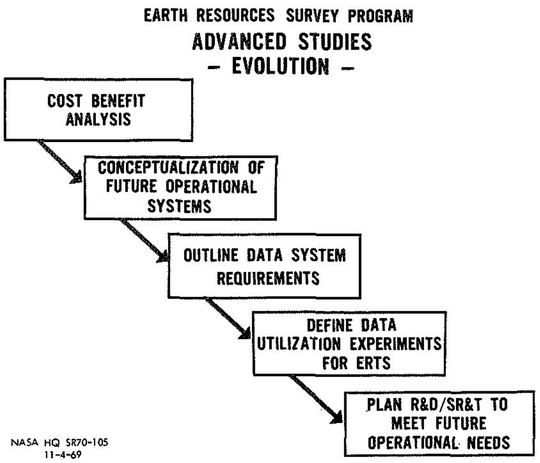


Figure 48

conceptualization and study of these future operational systems have been useful in providing some insight into future data system requirements, into defining data utilization experiments for the forthcoming series of Earth Resources Technology Satellites (ERTS-A & B), and into planning a research program to meet future operational needs. Basically, these studies have provided a framework of the synthesis and analysis of future total operational systems and,for this purpose, may have more general application.

The initial studies analyzed five examples of hypothetical satellite-assisted operational application systems, (rice production management, wheat rust control, regional water management, Pacific tuna fishing, and malaria control) each utilizing a different sensor-platform system. Each system was "optimized" for its particular purpose; no attempt was made to derive a common hardware system which could accomplish more than one application. A later study, being done by Planning Research Corporation (NASA Contract NASW-1816), has analyzed in considerably more detail, three promising applications: regional water management, wheat production management, and wheat rust control. In this later study,a single hardware system has been conceptualized for performing all three applications. This study has been conducted with the general guidance of the interagency Earth Resources Survey Program Review Committee (ERSPRC). While full coordination has not yet been completed with the ERSPRC, cost-benefit relationships for such a future operational concept appear promising as indicated in Figure 49. The benefits and costs shown are the totals for an assumed 20-year operational period with both costs and benefits discounted at a 10% rate back to the year of investment decision.

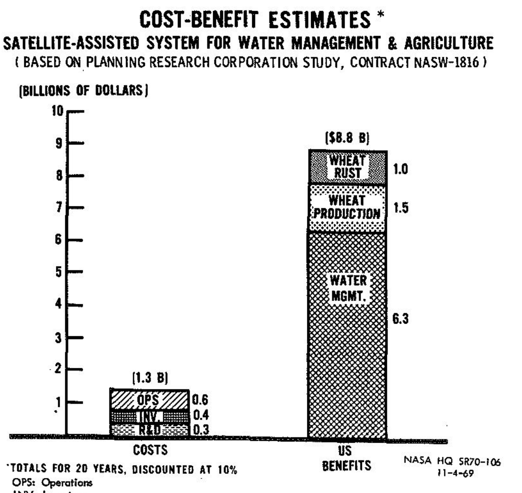


Figure 49

There are some important limiting assumptions in these studies which should be recognized. Some of these are as follows: (1) The conceptual systems employed spacecraft platforms only--no mixes of aircraft and spacecraft data gathering were considered since this would have excessively complicated the studies at this point, (2) The economic models employed were of necessity fairly rudimentary. Completely satisfying and applicable economic models are generally not available, and (3) A considerable amount of research and development has been assumed to have been accomplishable--and accomplished--in order to accept technical feasibility for the operational system concepts. In view of these considerations, the numerical cost-benefit estimates should be used with caution and are not necessarily the primary outputs of these studies.

Any realistic total operational system is not likely to be solely a spacecraft system nor solely an aircraft system, but will be, in all likelihood, a combination of a number of spacecraft, a number of aircraft and a considerable array of ground-based data-gathering capabilities as represented by river gauges, meteorological stations, ocean buoys and, possibly, balloons. All these information sources would have to be considered for incorporation into the total system.

A complete model of an operational ERS system must contain at least the essential elements shown in Figure 50. The observation systems (spacecraft, aircraft and ground-based) provide remote sensing data. These data, after processing, must serve as input to Earth-science-based models which can provide status interpretations and predictions of physical phenomena which, in turn, can be used by managers, by means of management decision models to determine management actions. The management decisions are also affected by non-physical inputs, e.g., in the political, economic, and social areas. Some of these latter factors can be taken into account principally in a qualitative way. The management actions are shown impacting on the resource problem. Natural phenomena also affect the resource problem but, as yet, we have no control over this input. The resource problem, as manifested by Earth conditions, is observable by means of the observation systems. It is clear, of course, that the impact of management actions on Earth conditions will often be modest in relation to the impact of natural phenomena. The elements shown in the Figure 50 represent the essential functional elements of any total Earth resources survey system. In most cases, it is important that the total closed loop system be considered if the requirements of the operational system are to be fully understood.

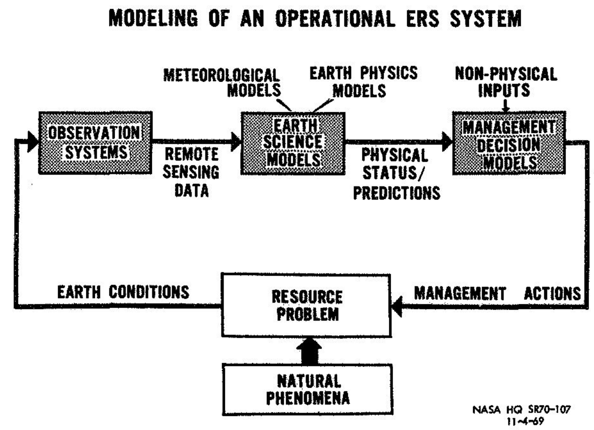


Figure 50

How can we provide an analytic framework for synthesis and analysis of these future systems? It is generally not feasible at this time to simply write down sets of differential equations which describe the dynamic behavior in each of the boxes shown in Figure 50. It has, however, been possible to develop what have been termed multi-stage "relevance matrices." These are illustrated symbolically in Figure 51 and have a one-to-one correspondence with the more conventional block diagram pieces shown in Figure 50. On the lower right of Figure 51 is shown, symbolically, the observation systems matrix which relates sensor capabilities to the measurements which can be made with these sensors of Earth conditions.

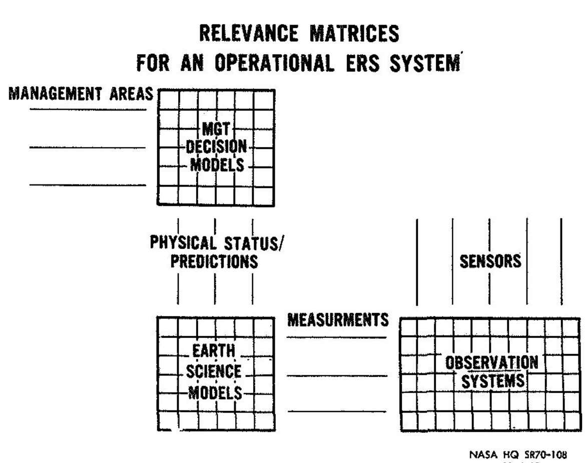


Figure 51

The Earth science model matrix relates these measurements to predictions and the management decision model matrix relates predictions to management and benefit areas. In each cell of these matrices it it possible to insert a number indicative of the state of knowledge and relevance for that cell. For example, the numbers in a column of the Earth science model matrix would indicate the present estimate of the potential relative contributions of each of the measurements to the prediction associate with the particular column.

A particular example from the regional water management case study is shown in Figure 52. This information, based on the case study of satellite-assisted regional water management, utilized the Bonneville Power Administration operation in the Columbia River basin as a core model for detailed analysis and subsequent extrapolation to the Pacific Northwest and, in applicable regions, to the entire U.S. In this matrix, the number "1" would denote a situation where a single input is "sufficient," by itself, to provide all data necessary for a single output. It is clear in this example, and in general, that there are no simple one-to-one causal relationships between a single input and a single output. For example, starting with the management decision matrix (upper left), we see that the implementation of an optimum drawdown-refill strategy (for cyclical dams) is dependent primarily on the availability of five predictions (shown by the "2's"). One of these five predictions, namely seasonal snowmelt runoff, is dependent on the list of measurements shown to the extent indicated in each cell, i.e., sufficient by itself (#1), major contribution (#2), or some contribution (#3). If we look at one of these measurements, snow area, we see that three sensors are utilized to infer this measurement. Snow temperature, on the other hand, is dependent on the thermal (IR) channel of the scanner. The assessments in the chart are dependent on technological capabilities assumed feasible for the operational time frame

EARTH RESOURCES SURVEY PROGRAM

RELEVANCE MATRICES FOR REGIONAL WATER MANAGEMENT STUDY

(SIMPLIFIED FOR EARLY OPERATIONAL CONCEPT)

MANAGEMENT AREAS	SEASONAL SNOWMELT RUNOFF	SEASONAL RAINFALL RUNOFF	STREAMFLOW: SURFACE	STREAMFLOW: GROUNDWATER	STREAMFLOW MAXIMA	STREAMFLOW MINIMA	LOAD VARIATIONS (POWER)
DRAWDOWN-REFILL STRATEGY	2	2	2	3	3	2	2
INTER-RESERVOIR COORDINATION	3	3	2	3	3	3	2
HEAD EFFICIENCIES AND HEDGE	3	3	2	3	2	2	2
FLOOD CONTROL	2	2	3	3	2	3	
IRRIGATION	2	2	3	2	3	3	

LEGEND
1. SUFFICIENT
2. MAJOR CONTRIBUTION
3. CONTRIBUTION

STATUS/PREDICTIONS

MEASUREMENTS	SEASONAL SNOWMELT RUNOFF	SEASONAL RAINFALL RUNOFF	STREAMFLOW: SURFACE	STREAMFLOW: GROUNDWATER	STREAMFLOW MAXIMA	STREAMFLOW MINIMA	LOAD VARIATIONS (POWER)
STREAMFLOW (ANTECEDENT)	3	3	2	2	2	2	
RAINFALL		2	2	2	2	3	
SNOW AREA	2		3	2	2	3	
SNOW WATER EQUIVALENT	2		3	2	2	3	
SNOW TEMPERATURE	3		3	3	3	3	
SNOW ALBEDO	3		3	3	3	3	
AIR TEMPERATURE	3	3	3	3	3	3	2
GROUND TEMPERATURE	3	3	3	3	3	3	
SOIL MOISTURE	3	2	2	2	2	3	
EVAPOTRANSPIRATION	2	2	2	3	3	3	
CLOUD COVER							2

SENSORS

MEASUREMENTS	MULTISPECTRAL TELEVISION	MULTI-SPECTRAL SCANNER	RADAR	MICROWAVE RADIOMETER	IR SCANNER
STREAMFLOW (ANTECEDENT)	3	3	3		
RAINFALL	3		2	3	3
SNOW AREA	2	2/3	2/3	3	3
SNOW WATER EQUIVALENT	2/3	2/3	2/3	3	3
SNOW TEMPERATURE		2		3	2
SNOW ALBEDO	2/3	2			
AIR TEMPERATURE		2		2	2
GROUND TEMPERATURE		2		2/3	2
SOIL MOISTURE	2/3	3		2	2/3
EVAPOTRANSPIRATION		3		2/3	2/3
CLOUD COVER	1/2	1/2			1/2

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Figure 52

selected and are, of course, subject to some debate. However, one can infer from the observation system matrix (Figure 52, lower right) that the multispectral scanner is a key sensor in this application and should receive appropriate R&D funding. Fortunately this has been reflected in the summary of instrumentation R&D efforts previously presented.

Through the use of modeling techniques supported by multi-stage relevance matrices, it has been possible to develop a practical format and analytical framework for synthesizing and examining future operational Earth resources survey systems. Most importantly, this analytical framework gives promise of: (1) being useful in planning the extensive R&D which must preceed future space-assisted operational management of dynamic Earth phenomena and (2) providing a basis for design of data utilization experiments for R&D spacecraft systems such as the planned Earth Resources Technology Satellites (ERTS).

In addition there are three other conclusions which appear significant: (1) there is a critical need for development of Earth-science-based models which can make effective use of the synoptic, repetitive data characteristic of spacecraft systems, (2) the presently programmed ERTS flight systems (ERTS-A & B) will provide an outstanding opportunity to develop and validate parameters of these essential interpretive and predictive models, and (3) in many cases of dynamic Earth phenomena, e.g., water management and agriculture, there is a first order interaction between meteorological models and Earth-science-based models. This relationship requires careful attention in examining any future operational Earth resources survey systems.

V. NASA-SPONSORED SUMMER STUDY ON SOLID EARTH AND OCEAN PHYSICS

An important development during the past year has been the recognition of the significant relationships between Earth and ocean physics and the space-based precision tracking capabilities emerging from the NASA-managed National Geodetic Satellite Program.

This recognition led to the sponsorship by NASA, during August 1969 of a two-week Summer Study on Solid Earth and Ocean Physics at Williams College, Williamstown, Massachusetts. The purpose of the Summer Study was threefold: (1) to identify important problems relating to the dynamics of the solid Earth and the oceans whose solutions would be facilitated by the application of space technology and precision, space-oriented, measurement techniques (2) to assess the value of the application of the precision measurement techniques in terms of furthering fundamental understanding of dynamic processes in the solid and liquid portions of the Earth, and in terms of attacking a wide variety of environmental problems; and (3) to indicate alternate approaches for studies and research, experiment definition, and problem evaluation (Figure 53).

Participation in the Summer Study was by invitation. The participants included U.S. and foreign scientists from geodesy, geology, geophysics, seismology, and physical oceanography discipline areas; scientists and engineers familiar with precision measurement techniques, and representatives from NASA Headquarters, NASA Centers, JPL, and ESSA.

**NASA-SPONSORED SUMMER STUDY
ON SOLID EARTH & OCEAN PHYSICS**

PURPOSE

- IDENTIFY PROBLEMS IN DYNAMICS OF THE SOLID EARTH & OCEANS FOR APPLICATION OF SPACE TECHNOLOGY AND PRECISION GEOMETRIC MEASUREMENT.
- ASSESS VALUE OF PRECISION GEOMETRIC MEASUREMENT FOR FUNDAMENTAL UNDERSTANDING OF DYNAMIC PROCESSES IN SOLID/LIQUID PORTIONS OF EARTH, AND FOR ENVIRONMENTAL PROBLEMS.
- INDICATE ALTERNATE APPROACHES FOR RESEARCH, EXPERIMENT DEFINITION, AND PROBLEM EVALUATION.

PARTICIPATION

- U.S. & FOREIGN SCIENTISTS FROM GEODESY, GEOLOGY, GEOPHYSICS, SEISMOLOGY, AND PHYSICAL OCEANOGRAPHY DISCIPLINE AREAS.
- SCIENTISTS & ENGINEERS FAMILIAR WITH PRECISION GEOMETRIC MEASUREMENT TECHNIQUES.
- REPRESENTATIVES FROM NASA HEADQUARTERS, NASA CENTERS, JPL, AND ESSA.

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Figure 53

The Summer Study emerged as an effective forum for an exchange of information among scientists with different interests and scientists and engineers experienced with precision measurement techniques. Several specific recommendations came out of the Summer Study--these will be contained in the Summer Study Report to NASA due for distribution during November 1969. A significant non-programmatic recommendation is for the establishment by NASA of an Earth Missions Board to allow for continued participation of scientists in the planning of NASA programs in solid Earth and ocean physics, meteorology, and Earth resources survey.

Most importantly, the relevance of space applications to solid Earth and ocean physics was defined as follows:

> to provide daily information on ocean currents at all depths, to understand the energy exchange between ocean and lower atmosphere, as required for longer-range weather prediction.
>
> to resolve the question of the relation of size of major earthquake events to changes in polar motion.
>
> to provide basic information on ocean tides in open ocean for fundamental understanding of the tidal deformation of the Earth and dynamics of Earth-Moon system.
>
> to provide direct measurements of crustal deformation, large-scale mass displacements, and continental drift, for understanding of processes within the core and mantle of Earth which are in large part responsible for tectonic processes such as fault motion, earthquakes, and volcano eruptions.
>
> to develop techniques for reliable warnings of catastrophic events, such as storm surges, tsunamis, and large-scale climatological changes.

Other words for definition of this relevance may be found in Figure 54.

**NASA-SPONSORED SUMMER STUDY
ON SOLID EARTH & OCEAN PHYSICS**

RELEVANCE OF SPACE APPLICATIONS TO SOLID EARTH & OCEAN PHYSICS

- CONTRIBUTES TO BETTER UNDERSTANDING OF DYNAMIC SOLID EARTH AND OCEAN PROCESSES
  - PERMITS CORRELATION OF DYNAMIC PROCESSES WITH NATURAL PHENOMENA SUCH AS EARTHQUAKES, VOLCANO ERUPTIONS, TSUNAMIS, STORM SURGES, CONTINENTAL DRIFT, OCEAN FLOOR SPREADING
    - PROVIDES CAPABILITY FOR PREDICTION OF MAJOR EARTHQUAKES, CATASTROPHIC VOLCANO ERUPTIONS, TSUNAMIS, AND STORM SURGES
      - PROVIDES INFORMATION FOR COMPUTATION OF GENERAL OCEANIC CIRCULATION ON DAILY BASIS, ON GLOBAL SCALE
        - CONTRIBUTES TO DEVELOPMENT OF TECHNIQUES FOR IMPROVED WEATHER PREDICTIONS AND LARGE SCALE CLIMATIC CHANGES

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Figure 54

VI. OVERALL INVOLVEMENT AND MANAGEMENT

EARTH RESOURCES SURVEY PROGRAM

NASA ORGANIZATIONAL INVOLVEMENT

PROGRAM ELEMENT	MSC	GSFC	OTHER	FUNDING FY70 $(M)
AIRCRAFT PROGRAM	●		●	11.0
SPACECRAFT PROGRAM				
ERTS A&B		●		14.1
ERTS C&D	○			–
ERTS E&F	○	○		–
ERTS FOLLOW-ON	○	○		
SATS		○	○	–
MANNED SPACEFLIGHT EXPERIMENTS				–
GEMINI/APOLLO	●	●		–
DWS/SPACE STATION	○	○	○	–
OPERATIONAL SYSTEM DEVELOPMENT	○	○	○	–
SUPPORTING RESEARCH & TECHNOLOGY	●	●	●	9.4
PERSONNEL LEVEL - FY70	274*	100	13	TOTAL 387
FUNDING LEVEL - FY70 $M	12.9	15.1		TOTAL 34.5**

* INCLUDES 179 CONTRACTOR PERSONNEL
** INCLUDES $6.5M PROGRAMMED VIA NASA HQ TO USER AGENCIES

● CURRENT
○ PROPOSED

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Figure 55

The overall involvement of NASA centers in the Earth Resources Survey Program is illustrated in Figure 55. The dominant role of MSC and GSFC is evident. It is anticipated that, when the SATS program is initiated and when experiments for the DWS-2, space station experiment modules and shuttle are initiated, the involvement will broaden significantly.

The distribution of funding by program element is summarized in Figure 56. Approved programs and runouts are differentiated from proposed programs. The proposed funding is based on an assumed FY 71 start for ERTS-C & D (film return) and an FY 72 start for ERTS-E & F (oceanographic). It is anticipated that projected follow-on ERTS and possible operational prototype systems will require a continued growth in total funding.

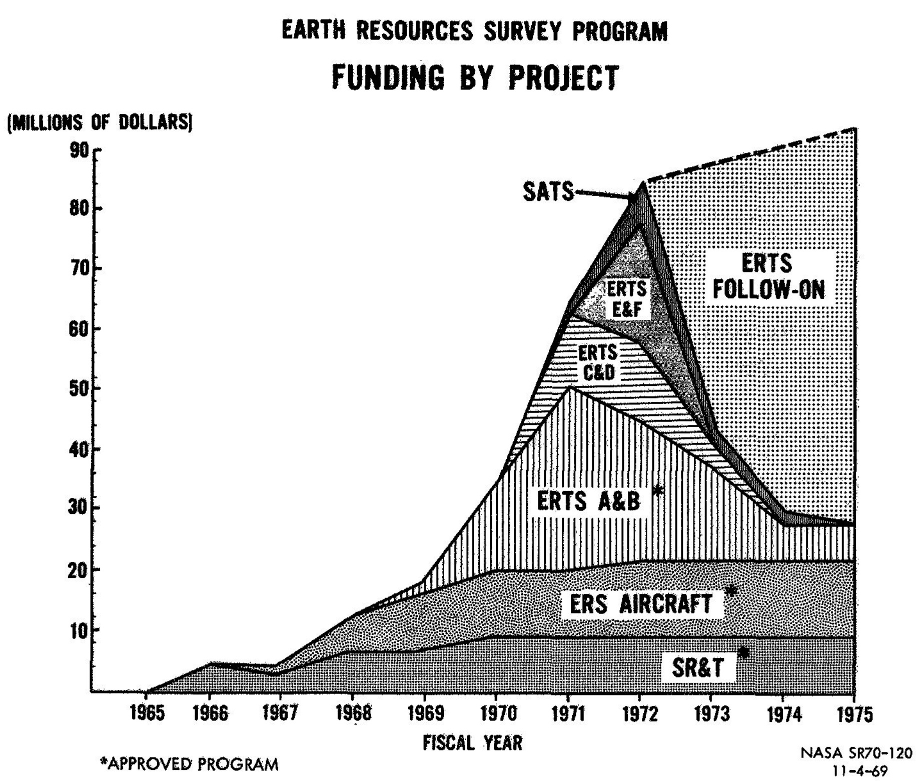

Figure 56

A significant accomplishment during the past year has been the continued development of the interagency Earth Resources Survey Program Review Committee (ERSPRC) as the primary vehicle for accomplishing interagency coordination for the ERS program (Figure 57). The function of the group is to review the total ERS program from a national and policy viewpoint and to deal with any substantive issues in the programmatic and policy areas. Representation is at or near the Assistant Secretary level from NASA, USDI, USDA, USDC and Navy Department. Arrangements have been made for attendance of observers from Bureau of the Budget, Marine Council, Space Council, Office of Science and Technology, and Department of Transportation. The committee has established two working subcommittees, one to guide and review systems and benefits studies and the second to deal with international matters. Among the action of the ERSPRC have been: (l) review and approval of specifications for ERTS-A & B, (2) development of a position paper on plans for international involvement in ERS for use by U.S. foreign service personnel and (3) supervision and coordination of a study of a satellite-assisted system for water management and agriculture.

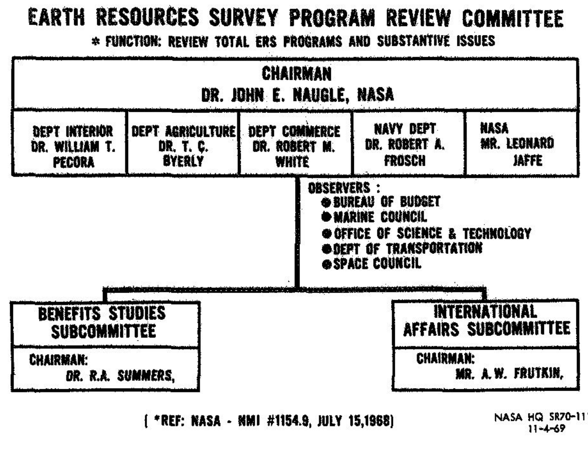

Figure 57

Figure 58 summarizes the history of transfer of NASA funds to the user agencies of the ERSPRC for the development of the ERS program. In addition, user agencies have been providing their own funds in support of earth resources survey. For example, the Department of Interior has allocated over $11,500,000 since 1964, and the Department of Agriculture has allocated nearly $2,750,000 during this same period. It has been agreed upon, at the ERSPRC level, that NASA transfer funds will begin to taper off during the next few years with the user agencies assuming the growing funding burden in their particular disciplinary areas. This curtailment of the need for transfer funds will permit NASA greater flexibility in funding of ERTS experiments.

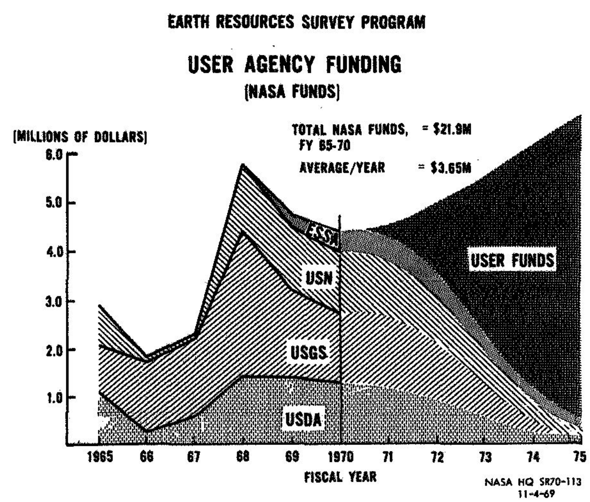

Figure 58

There has been, from the inception of the ERS program, a significant involvement of universities, their faculties, staffs and graduate students. The extent of this involvement is illustrated in Figure 59. Some 27 universities are involved spread over 23 states. The four principal centers are the University of Michigan, Purdue University, University of Kansas, and the University of California at Berkeley. While somewhat modest compared to the university effort in the sciences, these ERS-university involvements have played a vital role in supporting key research areas. For example, Purdue has been the lead research center in automatic digitized classification of Earth features, first for agriculture and now extending into geology and other disciplines. The group led by Dr. R. N. Colwell at Berkeley has pioneered in sensor-signature research in agriculture and forestry.

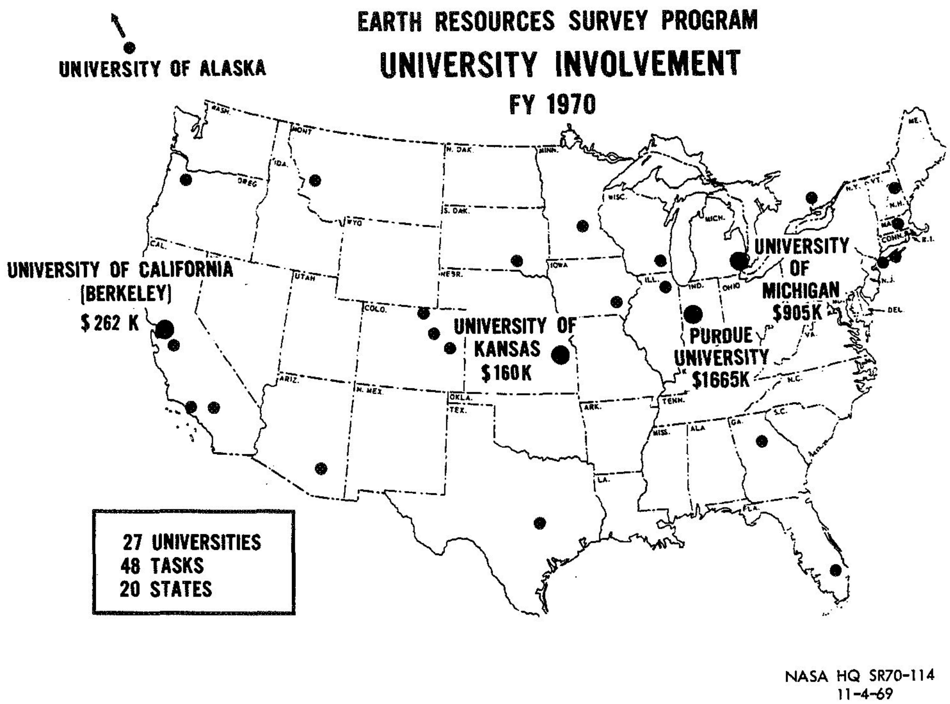

Figure 59

The distribution of ERS SR&T funds in FY 1970 is shown in Figure 60. It can be seen that approximately 45% of all SR&T funds eventually go to universities, 13% going directly from NASA and the balance via user agencies. The balance of 55% of SR&T funds is spent in industry or directly within the user agencies.

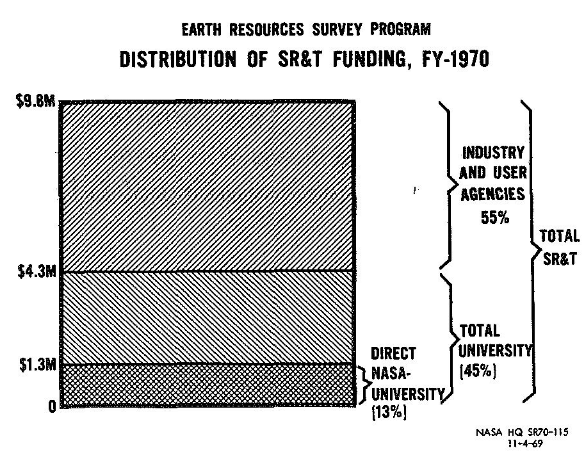

Figure 60

VII. SUMMARY

In summary, let us review some of the recent significant accomplishments in the ERS program. These are listed in Figure 61. We have conducted the first controlled multispectral photography from space which has verified the selection of spectral bands for ERTS-A & B. This experiment with its concurrent aircraft coverage has demonstrated the utility of combined spacecraft aircraft and ground coverage for multi-stage inventorying of resources. The associated sequential high-altitude multispectral photography through the growing season has demonstrated the feasibility of crop calendars to facilitate identification, as well as vigor, and yield estimation for crops. Continued success with automated digitized crop classification has been extended to geological features. The first dedicated ERS multi-sensor research spacecraft program (ERTS-A & B) has been initiated. The ERSPRC has been established as the vehicle for interagency coordination of programmatic and policy issues at a national level. Through our studies of total ERS systems, conducted under the cognizance of the ERSPRC, we have improved our understanding of total ERS system requirements including data handling and management. Through the recent NASA Summer Study we have improved our understanding of potential satellite applications to Earth and ocean physics.

EARTH RESOURCES SURVEY PROGRAM
ACCOMPLISHMENTS

- FIRST CONTROLLED MULTI-SPECTRAL PHOTOGRAPHY FROM SPACE
- COMBINED SPACECRAFT-AIRCRAFT COVERAGE FOR MULTI-STAGE ANALYSIS
- SEQUENTIAL HIGH-ALTITUDE AIRCRAFT COVERAGE DURING GROWING SEASON
- EXTENSION OF AGRICULTURAL AUTOMATIC DATA PROCESSING TO GEOLOGICAL FEATURES
- INITIATION OF ERTS A & B
- IMPLEMENTATION OF ERSPRC AS VEHICLE FOR INTERAGENCY COORDINATION
- IMPROVED UNDERSTANDING OF TOTAL ERS SYSTEM REQUIREMENTS
- IMPROVED UNDERSTANDING OF SATELLITE APPLICATIONS TO EARTH AND OCEAN PHYSICS.

NASA SR70-197
11-4-69

Figure 61

We feel that we have made substantial accomplishments towards the goal of establishing "a capability for responsible management of the Earth's resources and human environment."

But much remains to be done.

METEOROLOGICAL PROGRAMS

Presented by
Dr. Morris Tepper

I. INTRODUCTION

The influence of Earth's weather on man and his activities is clearly obvious. Each year our Nation suffers catastrophic losses of life and property as a result of such weather calamities as hurricanes, tornadoes, floods and blizzards. For example, it is stated in the Environmental Science Services Administration (ESSA) World Weather Program Plan document of this year that in 1966 alone the U.S. lost approximately one thousand lives and over one billion dollars to severe weather. It is quite probable that this toll could have been substantially reduced by longer range and more timely warnings combined with proper precautions. President Nixon, in forwarding this World Weather Program Plan to Congress stated, "Because so much of our social and economic life is significantly influenced by weather conditions, it is important that we encourage those advances in weather prediction and control which our scientists now foresee."

NASA has recognized the importance and urgency of this problem, and has stated, in a report for the Space Task Group, the following as the goals of the meteorological profession: "To understand the physics of the atmosphere, to bring about improved prediction of weather, and to establish a basis for eventual weather modification and climate control." (Figure I)

" TO UNDERSTAND THE PHYSICS OF THE ATMOSPHERE, TO BRING ABOUT IMPROVED PREDICTION OF WEATHER, AND TO ESTABLISH A BASIS FOR EVENTUAL WEATHER MODIFICATION AND CLIMATE CONTROL "

AMERICA'S NEXT DECADES IN SPACE
A REPORT FOR THE SPACE TASK GROUP
NASA, SEPT. 1969

NASA SR70-121
11-4-69

Figure I

Our present knowledge of meteorology is based on local weather observations--the observation of weather conditions at specific local points on the Earth's surface. From these local observations we can construct area charts showing weather conditions over large regions of the Earth. For example, Figure 2 depicts the weather conditions over North America on 17 August 1969, the date on which Hurricane Camille reached the Gulf Coast.

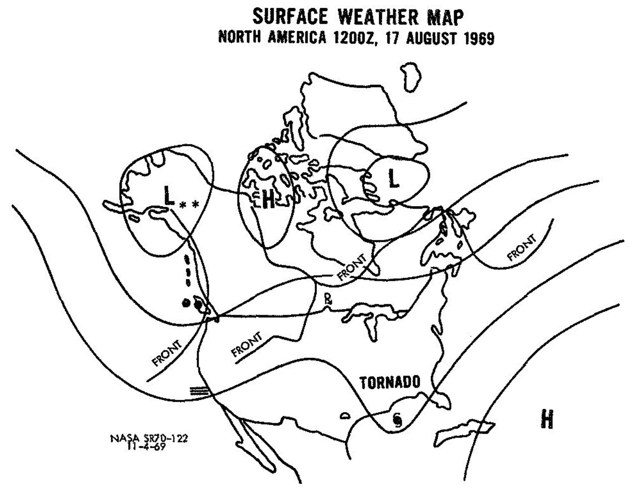

Figure 2

Figure 3 provides a pictorial legend for the wide variety of weather conditions in Figure 2. On that day there was a snow storm in Alaska, rain along the coast of the Pacific Northwest, and coastal fog in Southern California. In the Midwest, thunderstorms were reported in the Northern Plains, associated with a frontal system, while further south in Texas only fair weather cumulus clouds were observed. The most severe weather was found along the Eastern sector of the U.S., where electrical storms occurred in the Northeast, tornadoes were reported in the Southeast and Hurricane Camille was about to strike the Mississippi coast at Gulfport.

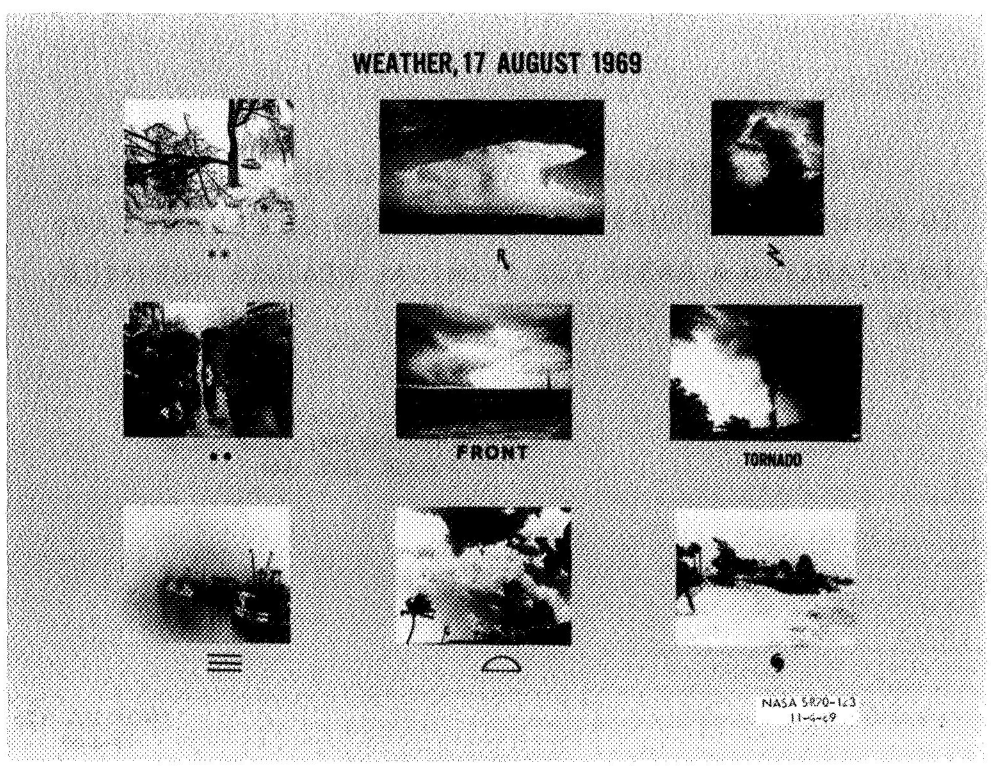

Figure 3

These variations in local weather--from snowstorm to sunny skies to tornadoes and hurricanes, all occurring within the United States on one particular day, are produced by variations in the upper air flow, as represented by the 500 millibar height contours in Figure 2, the curved lines overlying the surface weather map. Therefore, an understanding of the upper air flow is essential to an understanding--and prediction--of local weather conditions. However, as we can see from the Northern Hemisphere 500 millibar contour chart of this same date (Figure 4), the upper air flow over the United States is but one segment of the circulation pattern for the entire Northern Hemisphere. Therefore, to understand and predict airflow, and thereby, local weather conditions over the U.S., requires knowledge of the airflow over the entire hemisphere. This requirement becomes even more demanding as we attempt to predict weather conditions farther and farther into the future.

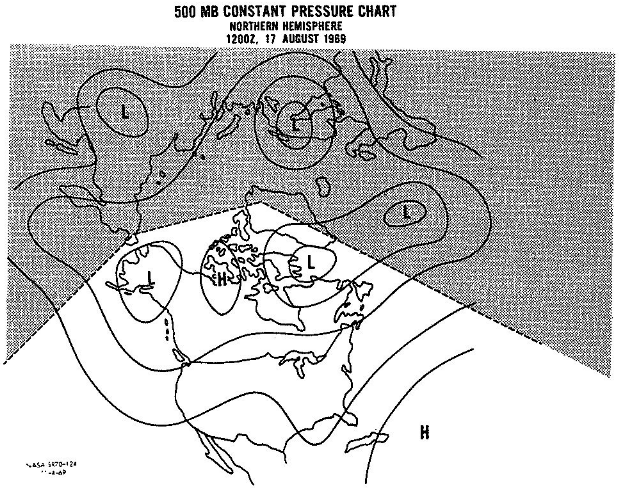

Figure 4

As we stated initially, our goal is not only to predict, but also to establish a scientific basis for future weather control. We have already achieved some degree of success in modifying weather as shown in Figure 5. Certain types of fogs have been successfully dissipated by the use of sodium chloride. Large holes in clouds have been created by using the down-wash from helicopters.

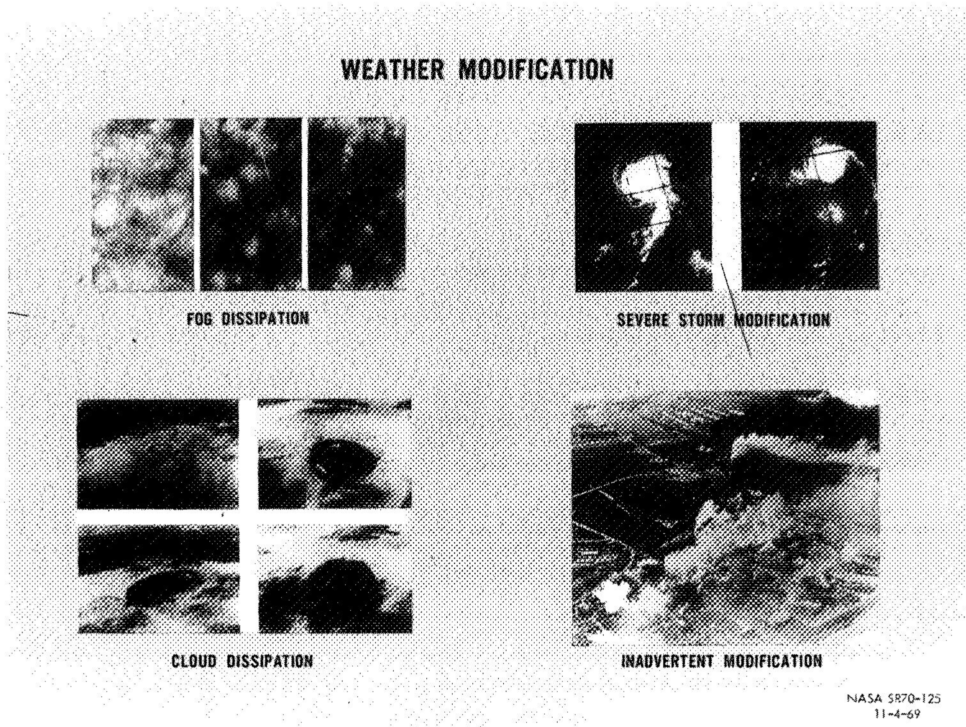

Figure 5

On a larger scale, the recent Hurricane Debbie was seeded in an attempt to modify its tremendous power; as can be seen in Figure 5, a significant reduction in its total size occurred, giving rise to hopes that we may indeed be able to influence these tremendous storms. And, of course, we must take note of the fact that man is inadvertently modifying the world's weather by the type and quantity of pollutants which he is introducing into the atmosphere. However, it should be apparent that our current capabilities of modifying the weather are limited essentially to local effects. Any success with large-scale weather control must first depend on a much better understanding and prediction of atmospheric processes than we now possess. We must know in advance and know accurately what the natural course of weather is to be, otherwise we shall be unable to recognize the results of weather modification attempts nor to measure its effect. Therefore, our goals of long-range prediction and eventual control of our weather are clearly dependent upon a better understanding of weather processes and an increased knowledge of global weather conditions. Space technology--the ability to observe Earth's weather from space--enables us to increase dramatically our knowledge of global weather conditions. This knowledge undoubtedly will lead to improved understanding of weather processes.

NASA plays an active and important role in the total meteorological program to achieve these goals, through the conduct of the national Meteorological Satellite research and development (R&D) program.

Our programs to fulfill the requirements for global meteorological data can be classified into three separate, but interrelated, objectives (Figure 6). The first objective, global cloud cover imaging, provides for the capability to periodically observe the global cloud cover; information which enables us to identify and track storms and to observe their formation and dissipation. Information of this nature is valuable in the analysis of current weather and the prediction of 24-36 hour changes. The second objective, continuous viewing of the atmosphere, provides the capability to keep significant portions of the Earth's cloud cover under constant surveillance, providing essential information on rapidly developing weather phenomena, such as thunderstorm and tornado formation, growth, and decay; information which is valuable for short-period (0 - 12 hours) forecasts. The third objective, global quantitative measurement of the atmospheric structure, will provide quantitative information of atmospheric parameters, such as the temperature,

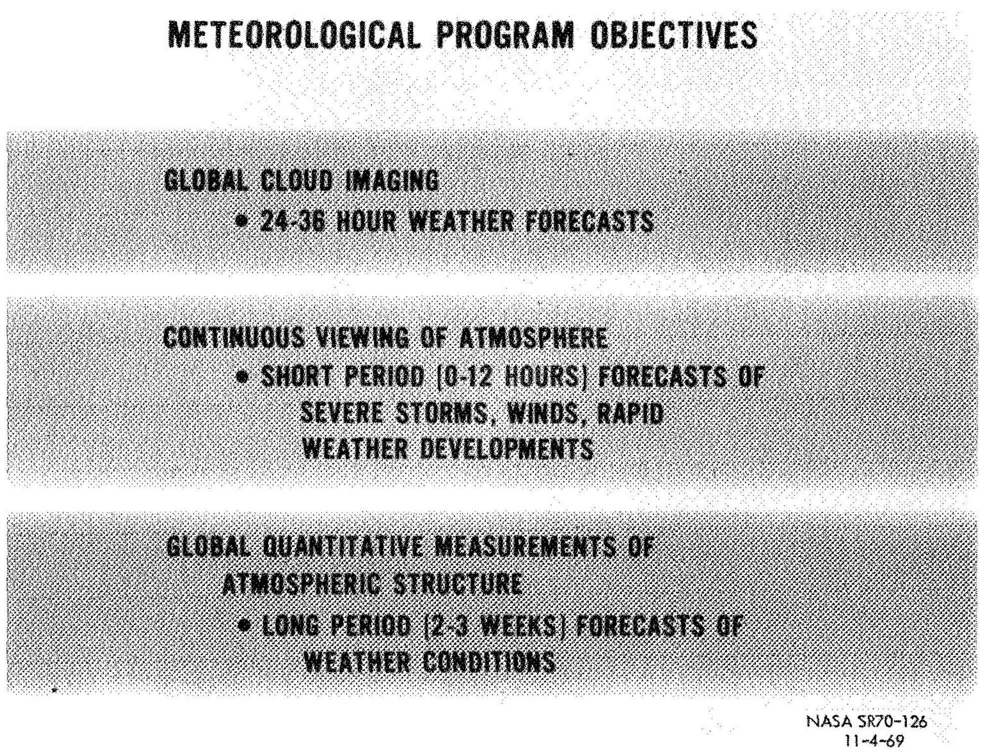

Figure 6

wind, water vapor; global information of the three dimensional structure of the atmosphere and its temporal variations. These data will vastly increase our knowledge of global weather conditions, increase our understanding of atmospheric processes, and, when used in conjunction with global mathematical models of atmospheric behavior, may make possible extended period (2 - 3 weeks) forecasts.

The NASA Meteorological Satellite Program has been designed against these stated objectives, and is being accomplished in this approximate order. The various satellite systems, past, present, and proposed, as they relate to each of the three major objectives are shown in Figure 7 in their relative time positions. Note that in general terms the TIROS satellites are associated with the first objective, the satellites in synchronous orbit are associated with the second objective, and the Nimbus satellites, with the third. We shall proceed to look at each of the three objectives and their flight programs in much greater detail. Also note that on the right of Figure 7 under 1975, we have the letters "G-A-R-P", which is the acronym for the Global Atmospheric Research Program. This program will be discussed in detail later but for now let it be noted that the ultimate objective of this international research program is the attainment of economically-useful, long-range predictions. It represents the next step in man's effort to predict the weather, and eventually to modify it for his own uses. It is the conduct of a comprehensive program of research to acquire a better scientific understanding of the physical and dynamic processes of the atmosphere for incorporation into prediction models. This requires quantitative global observations of the state and structure of the Earth's atmosphere. It is economically possible only through the development and utilization of the capabilities of meteorological satellites.

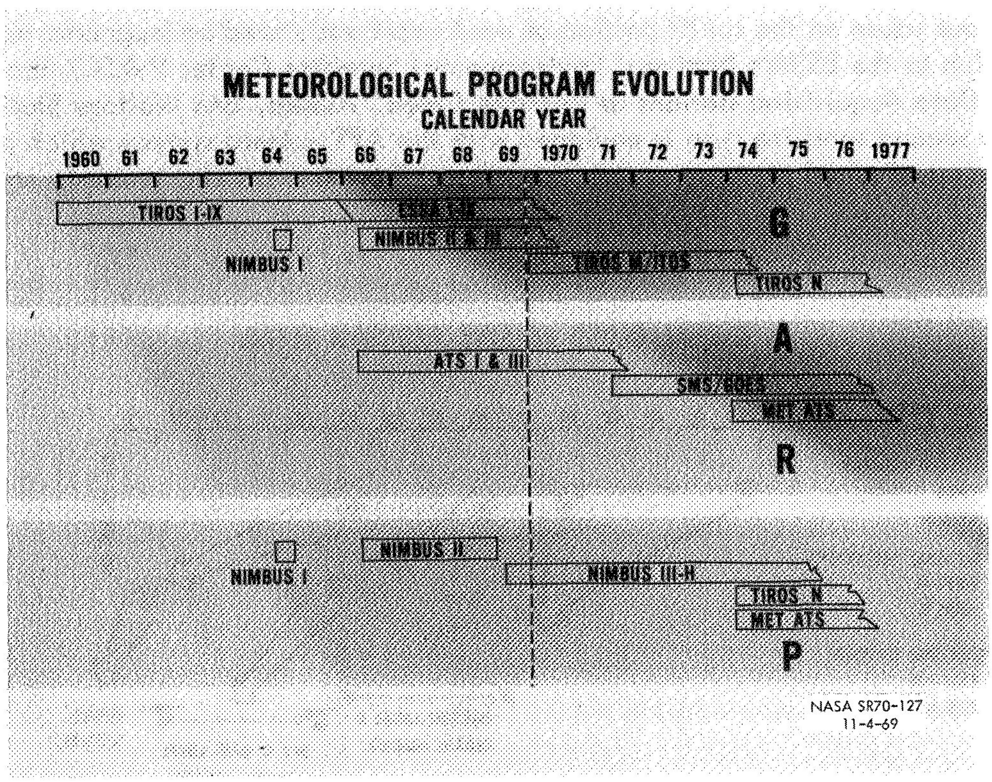

Figure 7

We have discussed the meteorological goals and the meteorological satellite program objectives. Now we wish to present in somewhat greater detail our program plans to achieve these objectives.

III. GLOBAL CLOUD COVER PROGRAM

The program elements of the global cloud cover program (Figure 8) are: (1) Our R&D flight program based on the TIROS and early Nimbus meteorological satellites; (2) The operational prototype spacecraft, TIROS-M and later TIROS-N; (3) The operational satellite systems funded and managed by the Department of Commerce (DOC), ESSA-I through X and ITOS-A through G; and (4) Our TOS improvements program which currently includes the major improvement items listed on Figure 8.

The R&D flight program has consisted of the TIROS and early Nimbus satellites R&D program. The successive development of TIROS-I through X produced a family of meteorological satellites capable of viewing global cloud cover once daily (during daylight) in either a stored-data mode for global analysis or in direct readout mode for local usage. The Nimbus I satellite provided some essential sensors for this purpose: The Advanced Vidicon Camera System (AVCS) for global coverage and the Automatic Picture Transmission (APT) Camera System for local coverage. The early TIROS and Nimbus R&D flight program led to the first operational meteorological satellite system--the TIROS Operational System, or TOS. The TOS program requires the continued operation from each of two satellite types. The first type is equipped with AVCS cameras to provide daily global picture coverage for central weather analysis and forecasting use. Pictures are taken on the sunlit portion of each orbit and stored on magnetic tape for later transmission to the ESSA's National Environmental Satellite Center (NESC) through the Command and Data Acquisition stations at Gilmore Creek, Alaska, and Wallops Station, Virginia. The second satellite type is equipped with the APT camera systems which provide immediate readout of cloud pictures as they are taken. From this system, properly equipped

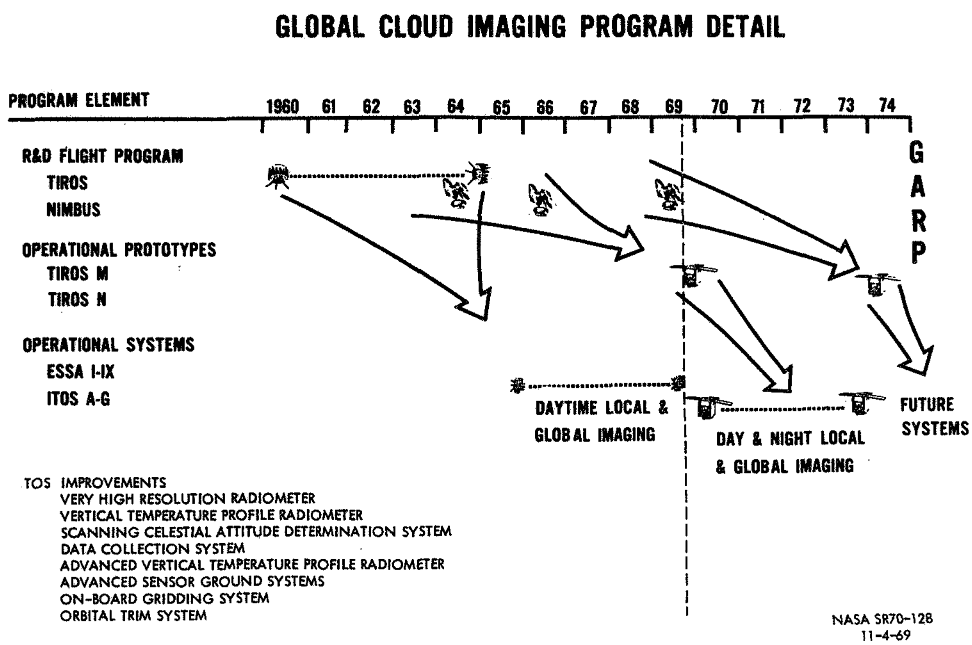

Figure 8

stations (more than 500 stations over the world) can receive cloud pictures covering a region within about 2,000 miles of the stations. Both types of satellites are flown in circular, sun-synchronous orbits at an altitude of 790 nautical miles, and carry redundant systems designed to extend the useful life of the satellite.

Figure 9 depicts the performance history of the meteorological satellite program, revealing that since inception of each of the two types of satellites--stored data (AVCS) and direct readout (APT), almost continuous performance has been provided. The only exceptions are the brief intervals between TIROS-I and II and between TIROS-III and IV in the earliest days of the stored data program. The cloud cover data from these satellites have provided valuable information for analysis and prediction of weather conditions, and have become an essential element of our national weather service.

OPERATIONAL UTILIZATION OF METEOROLOGICAL SATELLITES

– PERFORMANCE HISTORY –

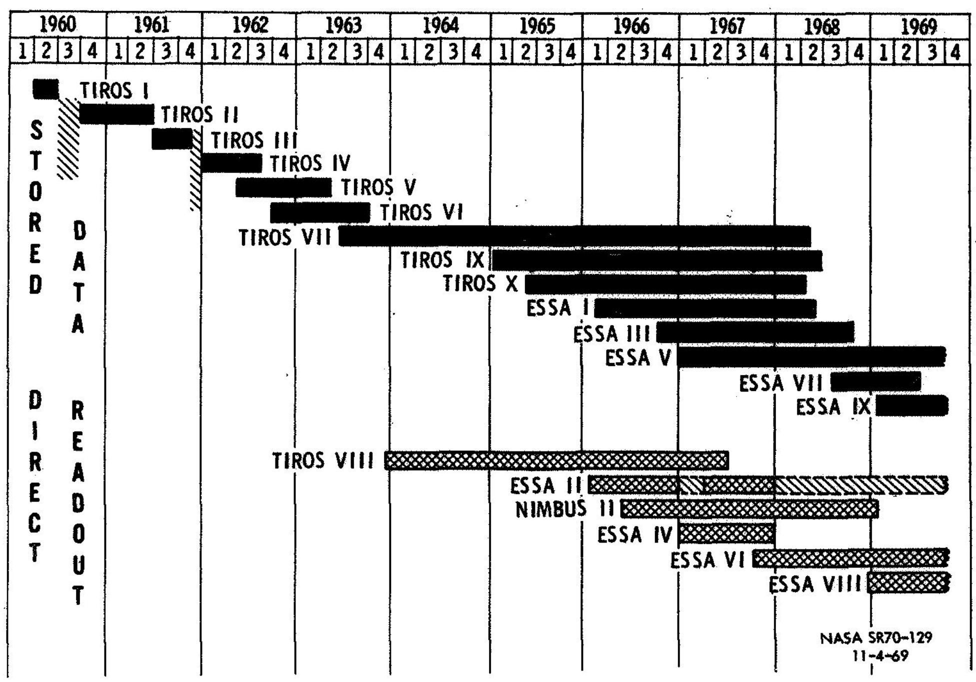

Figure 9

Figure 10 cites several examples in which AVCS and APT data have proven particularly valuable in operational situations. The cloud cover photograph shown is the product of the APT station which the U.S. provided to the Mexican Government. Photos such as these are sent daily to 17 Mexican departments. The value of satellite data was graphically proven to Mexico on the occasion when continued heavy rains threatened to destroy a dam. To relieve the pressure on this dam, it was proposed to open the flood gates which would, it was realized, destroy a small village downstream from the dam. Satellite photos indicated that rain would stop prior to the danger point, and therefore, neither the dam nor the village were endangered. Based on similar data, the hospital ship "HOPE" was rerouted, to avoid a developing storm at sea; aircraft crews are routinely provided with a specially prepared montage of geography, cloud photographs and cloud analyses detailing weather conditions for transatlantic flights; both cloud cover photographs and a specially prepared snow and ice field chart are used by U.S. Coast Guard ice breakers and the S.S. Manhattan in its recent voyage through the Northwest Passage to Prudhoe Bay. In the recent Barbados Oceanographic Meteorological Experiment (BOMEX) conducted by the Department of Commerce, Department of Defense, NASA, and other agencies, satellite cloud cover data were gathered in conjunction with conventional surface, upper air, radar, and aircraft reconnaissance data in a concerted effort to improve our knowledge of tropical meteorology. The value of satellite photos, in detecting and tracking of hurricanes is obvious; cloud cover imagery led to the initial detection of Hurricane Debbie when the Weather Bureau's full attention, and all of its reconnaissance aircraft, were being directed to the impending violence and destruction of Hurricane Camille as it moved in on the Gulf Coast.

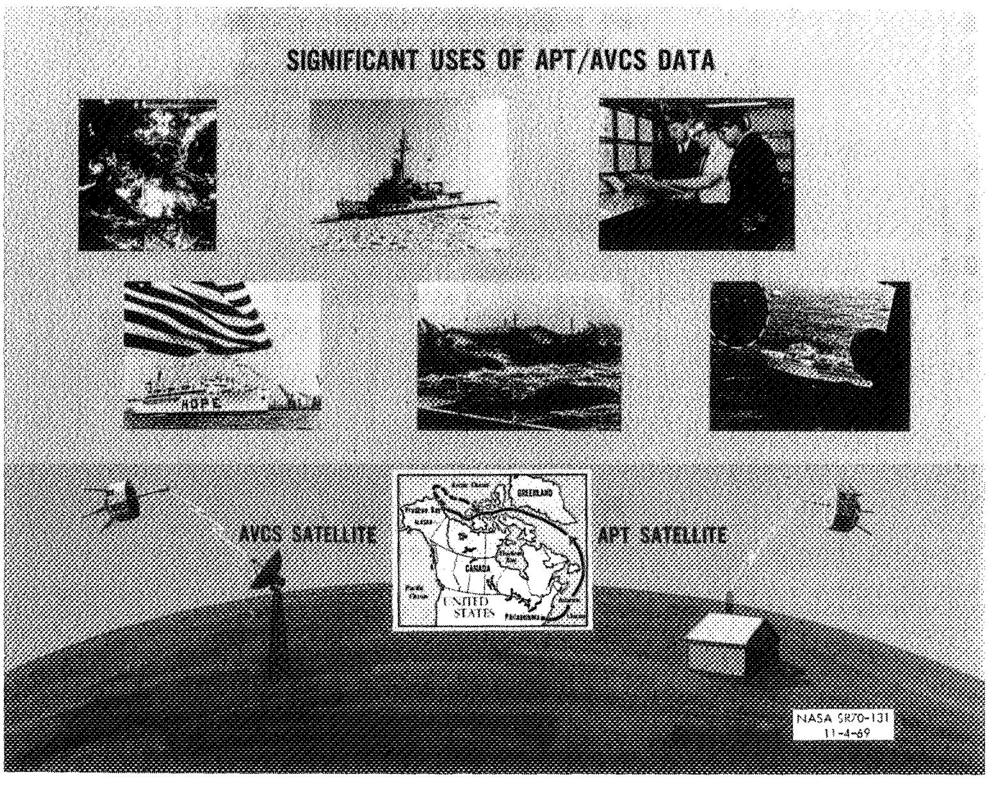

Figure 10

The United States and the USSR have established the Washington-Moscow bilateral circuit depicted in Figure 11 for the exchange of both conventional meteorological charts and meteorological satellite data. Bilateral discussions led to the first exchange of meteorological data over this circuit on 28 October 1964.

The U.S. transmits ESSA AVCS pictures and nephanalyses (cloud analyses) of the north and equatorial Atlantic areas, equatorial Africa, and Eurasia, plus conventional meteorological charts. In return, the Soviet Union sends selected cloud cover pictures, nephanalyses and actinometric (radiation) charts, plus conventional meteorological charts. The cloud cover pictures are not over the same areas every day. Examples of the data transmitted to USSR are shown on Figure 12. Figure 13 shows examples of the Russian data. A one-for-one qualitative comparison should not be made, for the U.S. data represents copies of original photographic products, while the Russian data are copies of products received by facsimile machine after radio and cable transmission.

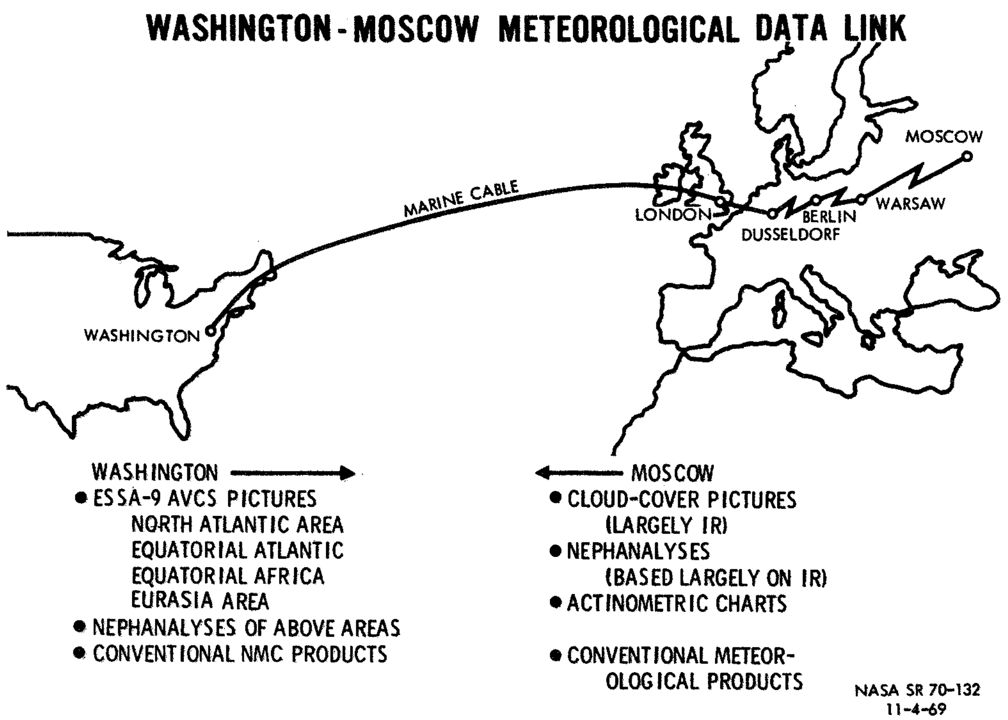

Figure 11

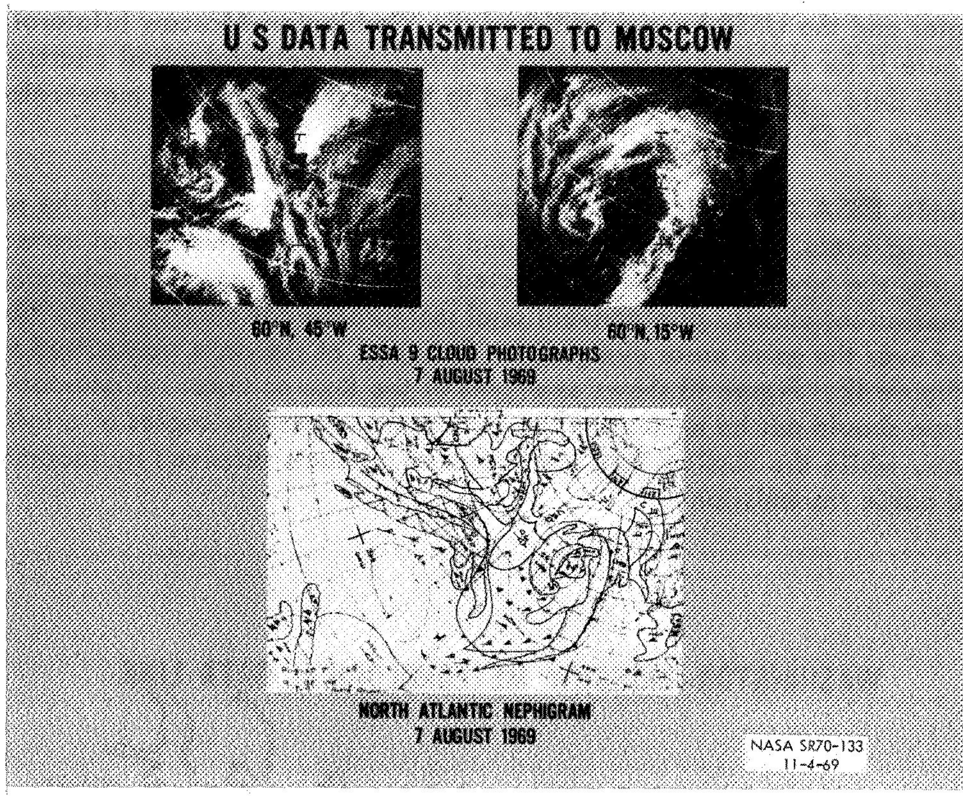

Figure 12

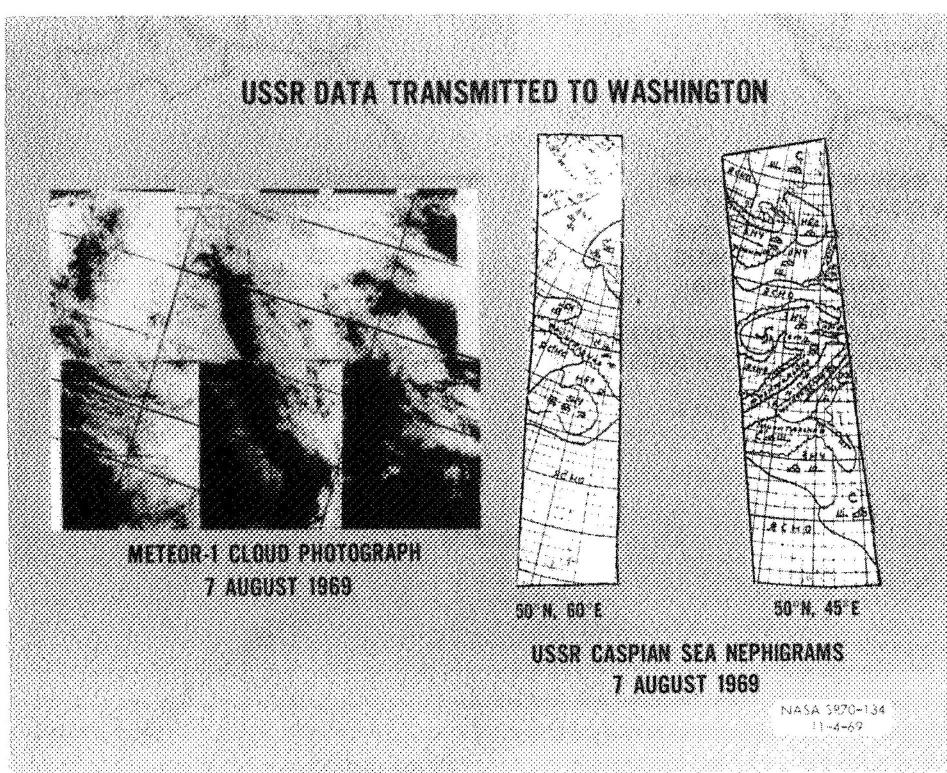

Figure 13

The chronology of this meteorological data link is shown in Figure 14. As noted, transmissions of U.S. data to the USSR of TIROS/ESSA data commenced in 1966, and conventional data in 1964, continuing without interruption since those dates. The USSR has transmitted conventional data continuously since 1964; however, transmission of satellite data has been interrupted on several occasions.

We have now reviewed briefly the history of establishment of the operational system for global cloud imagery, and have discussed the use and importance of this data. Now let us look to the future.

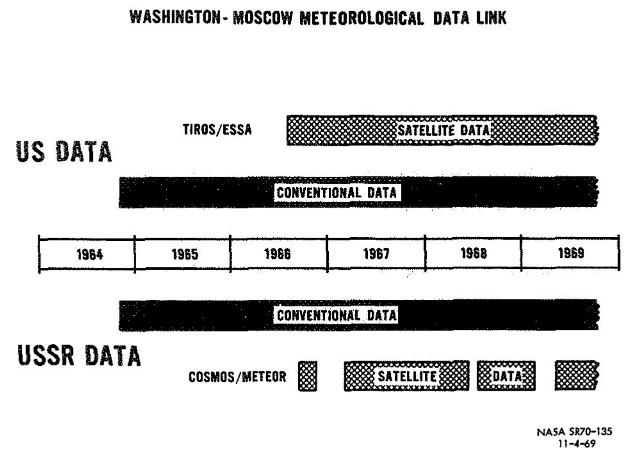

Figure 14

As shown on Figure 15 a new system, TIROS-M, will combine in one satellite the capabilities of the existing TOS system and the nighttime infrared (IR) cloud cover imagery capability developed in the Nimbus program. TIROS-M is in effect an operational prototype for an Improved-TOS Operational System (ITOS). TIROS-M will be launched soon, and the improved TOS system is scheduled to follow next year.

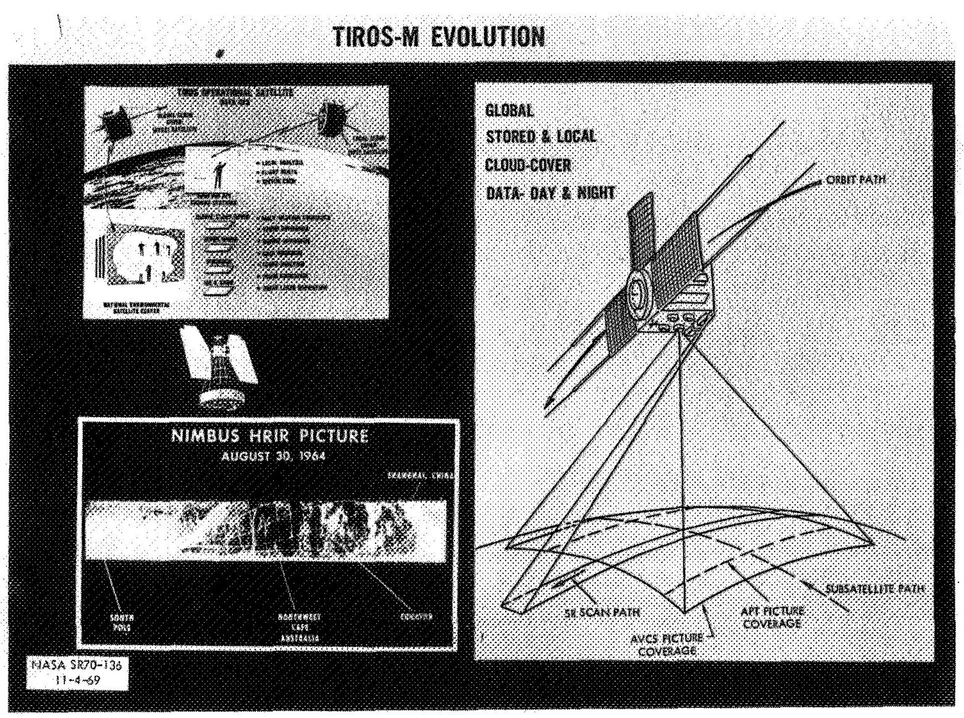

Figure 15

Planning for the TIROS-N, the second of the two operational prototype systems shown on Figure 8, will be primarily concentrated on appropriate spacecraft modifications to the TIROS-M design in order to accommodate new instrument payloads suggested in the Nimbus R&D flight program.

In addition to the development programs of the spacecraft themselves, we are conducting a specialized program to develop certain sensor, ground station, and other subsystems tailored particularly for the operational system. These developments, called the TOS Improvements Program, are designed to solve special problems and, as appropriate, will be incorporated in the TOS program.

IV. CONTINUOUS VIEWING OF THE ATMOSPHERE

The second objective, continuous viewing of the atmosphere (Figure 16) is also addressed in the three program elements of (1) R&D flight programs, based on the Applications Technology Satellite (ATS) multi-purpose satellites; (2) The operational prototype spacecraft Synchronous Meteorological Satellite (SMS); and (3) The operational satellite system Geostationary Operational Environmental Satellite (GOES).

This R&D flight program benefited from NASA's ATS program. The communications satellite, Syncom, established the fact and feasibility of geostationary orbits, in which satellites appear to remain stationary with regard to the subsatellite point. Using this technology, the ATS satellites exploited the advantages of this constant Earth-satellite relationship as demonstrated in Figure 17. ATS-I, launched on 7 December 1966, was placed in orbit over the Pacific Ocean Basin at the Equator and 151° West Longitude, and is in operation to this day. ATS-III was launched on 5 November 1967, and is also in operation today over the Atlantic Ocean at the Equator and 47° West Longitude, just off the East Coast of South America. In early 1968, it was temporarily moved to 95° West so that severe storms over North America could be monitored. The major experiment on both of these satellites is the spin scan camera capable of providing an image of the Earth's disc every 20 minutes. Secondary experiments include the WEFAX data collection and Omega Position Location Experiment, which are concerned with the collection and transmission of meteorological data, and have successfully demonstrated the feasibility of these concepts for use in future weather systems.

The capability to produce cloud cover images every 20 minutes provides material to study the formation and movement of significant weather systems, to derive wind information from cloud motion, and to view the dynamics of atmospheric motions.

As a demonstration of the value of ATS photographs for analysis of dynamic atmospheric processes, it is possible to combine sequential ATS photos into a time-lapse movie, revealing dramatically "Weather in Motion." A short film clip, prepared under NASA contract by Dr. Fujita of the University of Chicago, reveals examples of intense local cloud activity in South America, an East Coast snowstorm, tornado activity, "hook-cloud" formations (noted to be associated with tornado incidence), jet stream motions, and Hurricanes Candy and Camille--all made all the more graphic by the "Weather in Motion" feature of the movie.

ATS-D was launched on 10 August 1968, carrying camera systems with a potential for both day and night cloud viewing. A malfunction of the launch vehicle's second stage left the satellite attached to the vehicle and in a highly elliptical orbit and no useful meteorological results could be obtained.

ATS-F, whose launch is scheduled for Calendar Year 1972, will provide additional developmental support for a future geostationary meteorological satellite system. We are also planning for a dedicated ATS meteorological satellite in synchronous orbit, "MET-ATS," which will serve as a platform for continuing our R&D in the continuous viewing of the atmosphere from space.

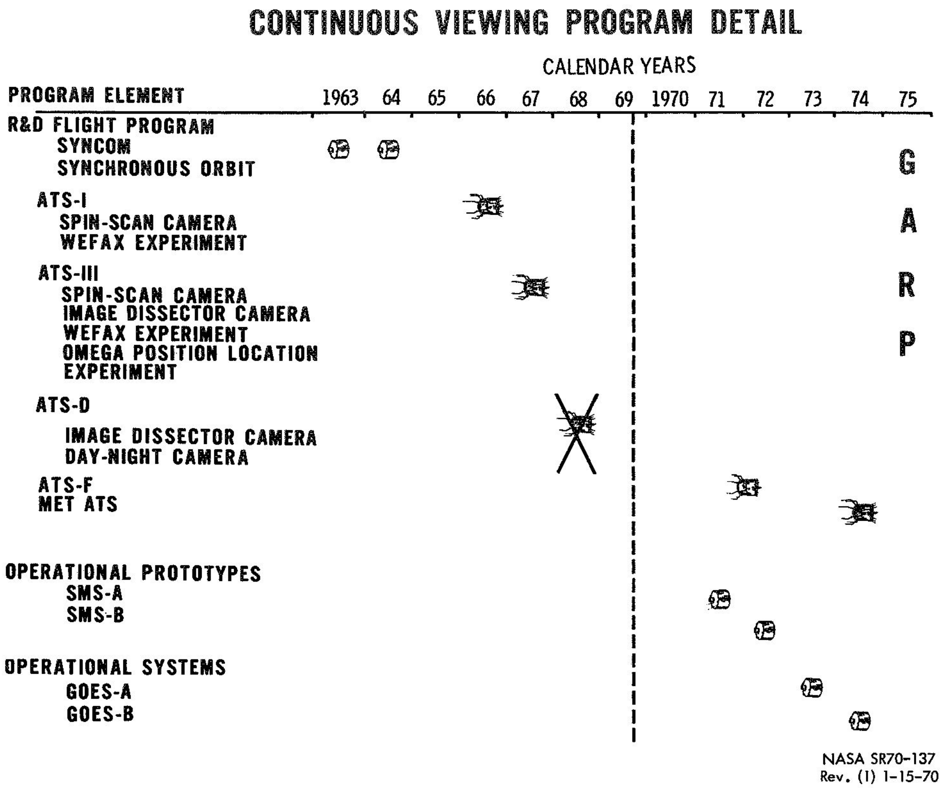

Figure 16

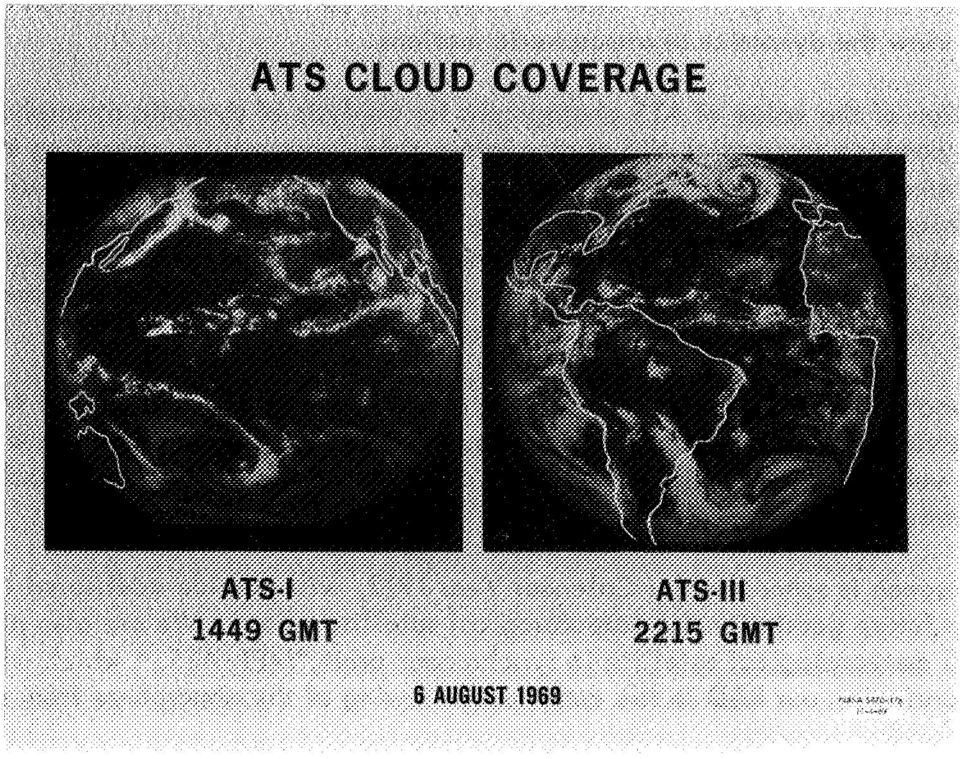

Figure 17

Cloud cover pictures, obtained with the ATS-I and III satellites during the past two years, have convincingly demonstrated the tremendous potential of continuous observation. Considering the utility of these data and the fact that no new technology is required, it is our plan to initiate the development of a prototype operational Synchronous Meteorological Satellite (SMS-A, Figure 18) in FY 1970. This effort could lead to the launch of such a prototype in early CY 1972. An operational capability thus implemented will permit continuous observation of major weather systems, routinely enhancing our ability to predict and locate short-lived storms. The analysis of cloud motions, through such observations, will permit the derivation of important wind fields over a considerably larger area and in much less time than presently possible.

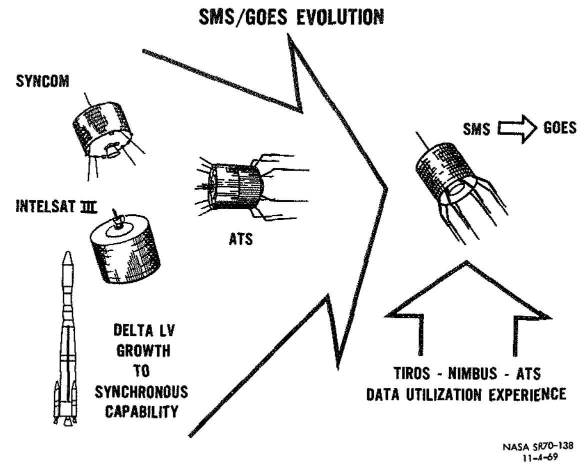

Figure 18

The satellites of the operational system, GOES-A and B, would follow the successful launch of the prototype satellites SMS A and B and will take their place as part of this nation's National Operational Meteorological Satellite System.

V. QUANTITATIVE MEASUREMENT OF THE ATMOSPHERIC STRUCTURE

Figure 19 presents the flight program of the third objective, quantitative measurement of the atmospheric structure. Here also the program can be divided into (1) The R&D flight program; (2) Operational prototypes; and (3) Operational systems. The magnitude and complexity of quantitatively determining the many meteorological parameters using remote sensors are orders of magnitude greater than the relatively simpler task of viewing cloud cover. Dramatic developments have been made toward this objective, but we are still in the R&D phase and considerations of an operational system are limited to a select few parameters.

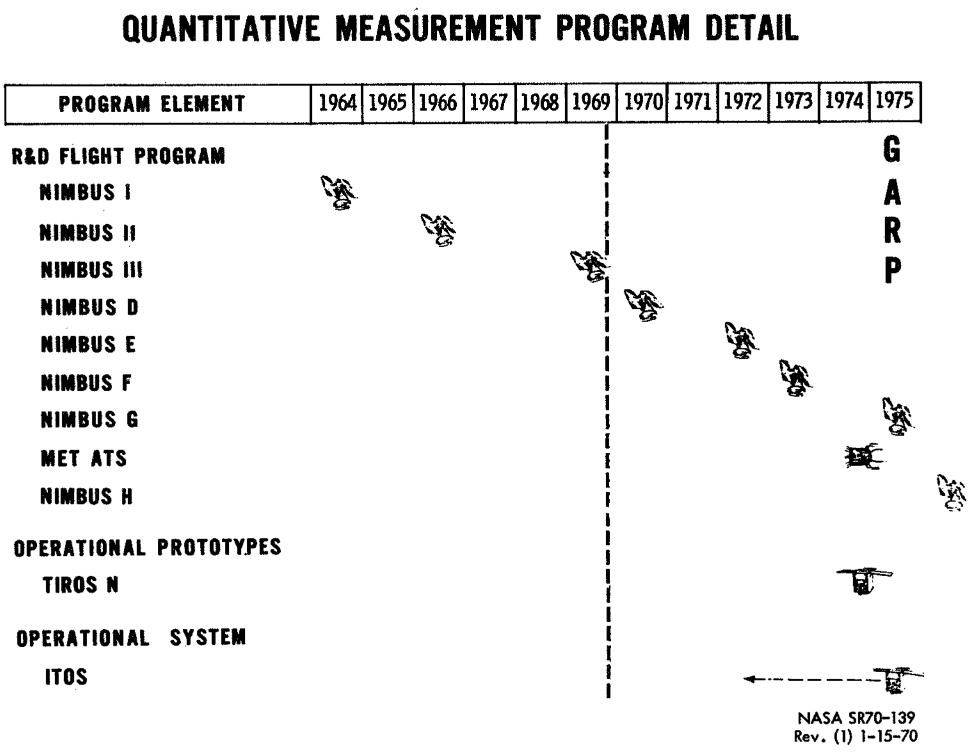

Figure 19

For these reasons, our discussion of this objective will concentrate essentially on the Nimbus R&D program, with only a brief mention of future operational systems which can incorporate quantitative sounding sensors developed in the Nimbus program. Although shown for 1975, we are considering incorporating a first version of an atmospheric sounder on an earlier ITOS.

The growth of the Nimbus program is depicted in Figure 20. Nimbus I and II, launched in 1964 and 1966, were essentially devoted to development and test of cloud cover mapping in the visible and IR spectral bands. Note in Figure 21 the sensors which have already been mentioned in the TOS/ITOS programs.

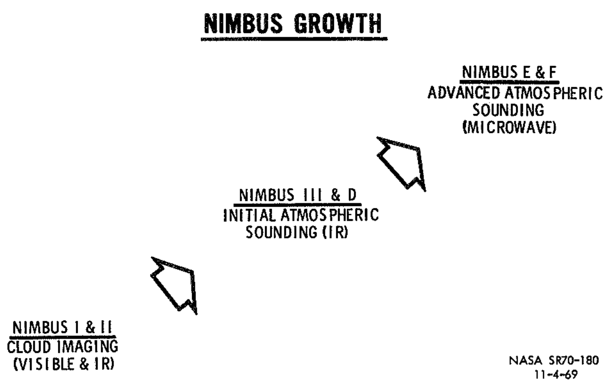

Figure 20

NIMBUS GROWTH

CLOUD IMAGING-VISIBLE & IR

NIMBUS I	NIMBUS II
• ADVANCED VIDICON CAMERA SYSTEM (AVCS)	• AVCS
• AUTOMATIC PICTURE TRANSMISSION (APT) CAMERA SYSTEM	• APT
• HIGH-RESOLUTION INFRA-RED RADIOMETER (HRIR)	• HRIR
	• MEDIUM-RESOLUTION INFRA-RED RADIOMETER (MRIR)

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Figure 21

Nimbus III, launched on 14 April 1969, and Nimbus D (Figure 22) scheduled for launch in 1970, represent our first concentrated efforts to quantitatively measure the atmospheric state parameters. Primary emphasis is placed on IR sensors, such as the satellite IR spectrometer (SIRS) and the Infrared Interferometer Spectrometer (IRIS), for the determination of temperature, water vapor and ozone content. Another important method for obtaining global quantitative data of the atmosphere is the Interrogation, Recording and Location System (IRLS) tested on Nimbus III and included on Nimbus D. This system is essentially a data system which interrogates selected sensor platforms, acquiring the meteorological data and at the same time electronically determining the exact location and identification of the platform. Other sensors on Nimbus III include a Monitor of Ultraviolet Solar Energy (MUSE) and an Image Dissector Camera System (IDCS) for viewing cloud cover. Nimbus D will contain improved versions of the sensors indicated on Nimbus III, and will also provide experimental test of additional IR sounding sensors.

NIMBUS GROWTH

ATMOSPHERIC SOUNDING-IR

NIMBUS III	NIMBUS D
• INTERROGATION, RECORDING & LOCATION SYSTEM (IRLS)	• TEMPERATURE & HUMIDITY INFRA-RED RADIOMETER (THIR)
• RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG)	• BACKSCATTER ULTRAVIOLET SPECTROMETER (BUV)
• IMAGE DISSECTOR CAMERA SYSTEM (IDCS)	• FILTER WEDGE SPECTROMETER (FWS)
• INFRA-RED INTERFEROMETER SPECTROMETER (IRIS)	• SELECTIVE CHOPPER RADIOMETER (SCR)
• SATELLITE INFRA-RED SPECTROMETER (SIRS)	• IRLS
• MONITOR OF ULTRAVIOLET SOLAR ENERGY (MUSE)	• IDCS
• MRIR	• IRIS B
• HRIR	• SIRS B
	• MUSE

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Figure 22

The next major milestone in our program to quantitatively measure the structure of the atmosphere will occur with the launch of Nimbus E and F in 1972 and 1973. These satellites will make the first exploratory use of the microwave region of the spectrum for atmospheric sounding. The microwave spectral band offers real promise to meteorology for the reason that microwave radiation is not obscured by ice clouds or by water droplets (if their size and number are not large), thereby giving the possibility of measuring the temperature structure despite cloud cover.

NIMBUS GROWTH

ATMOSPHERIC SOUNDING-MICROWAVE

NIMBUS E	NIMBUS F (CANDIDATE EXPERIMENTS)
• INFRARED TEMPERATURE PROFILE RADIOMETER (ITPR)	• MULTI-DETECTOR GRATING SPECTROMETER (MGS)
• MICROWAVE SPECTROMETER (MWS)	• CO_2 RADIOMETER FOR TEMPERATURE SOUNDING
• ELECTRICALLY SCANNING MICROWAVE RADIOMETER (ESMR)	• HIGH-RESOLUTION INFRA-RED RADIATION SOUNDER
• SURFACE COMPOSITION MAPPING RADIOMETER (SCMR)	• TROPICAL WIND MEASUREMENT
• REAL-TIME DATA RELAY (RDR)	• LIMB RADIANCE INVERSION EXPERIMENT
• THIR	• HEAT BUDGET EXPERIMENT
• SCR	• POSITIVE ION COMPOSITION
	• CIRCULAR ELECTROSTATIC PROBE STUDIES
	• SOLAR COSMIC RAY & TRAPPED PARTICLE EXPERIMENT
	• THIR
	• ESMR
NASA SR70-142 11-4-69	MWS

Figure 23

Nimbus E will carry two microwave experiments. The first is the Microwave Spectrometer (MWS), to measure atmospheric temperature at three levels between the surface and 18,000 meters altitude and the total liquid and water vapor content of the troposphere using the 5 mm band for temperature and the 1.35 mm band for water vapor. The second microwave experiment is the Electrically Scanning Microwave Radiometer (ESMR), which will map (globally and continuously) the thermal radiation from the Earth's surface and the atmosphere at a wavelength of approximately 1.55 cm.

In addition to the microwave experiments, Nimbus E will also contain IR sounders for comparison with the microwave sounders and also to advance IR technology. These will include the Temperature and Humidity IR Radiometer (THIR) carried on Nimbus D; an IR Temperature Profile Radiometer (ITPR), which will measure IR radiation in the 11 and 15 micron bands, providing high spectral resolution of 20 wave numbers and spatial resolution of 26 nautical miles; a Surface Composition Mapping Radiometer (SCMR) for providing information on the composition of the Earth's surface; and a Realtime Data Relay (RDR) to test the feasibility of using a polar-orbiting satellite to collect and relay data from synchronous satellites (ATS-F) and the feasibility of tracking low-orbit satellites by synchronous orbit satellites.

The tentative payload candidates for Nimbus F are in the selection process. From these candidates, a final selection will be made at a later date. The present list of possible experiments is as follows (Figure 23):

- A Multi-detector Grating Spectrometer (MGS) to provide higher temperature resolutions at low altitudes and temperature data from higher altitudes than possible with earlier IR sounders

- A Carbon Dioxide Radiometer to obtain temperature soundings from higher altitudes

- A High Resolution IR Sounder to provide spatial resolution capable of sounding the atmosphere through breaks in the cloud cover

- A Tropical Wind Measurement Experiment

- The Microwave Spectrometer of Nimbus E
- The Electrically Scanning Microwave Spectrometer of Nimbus E
- The Temperature and Humidity IR Radiometer of Nimbus D
- A Heat Budget Experiment to measure the heat flux into and out of the atmosphere
- Several space physics experiments being considered on a non-interference basis if the space, weight and power capabilities of Nimbus F are adequate.

Figure 24 gives our concepts for the Nimbus Follow-on Satellites, Nimbus G and H, which are currently under study. We are studying the application of advanced observing techniques for the analysis and survey of those boundary phenomena which impinge on the atmosphere, i.e., the Earth's land and sea surface. We expect also to study the upper atmosphere as it influences the weather below as well as the details of the cloud itself.

NIMBUS GROWTH

NIMBUS G&H CONCEPTS

APPLICATION OF ADVANCED OBSERVING TECHNIQUES FOR ANALYSIS & SURVEY OF ATMOSPHERIC PHENOMENA

- SEA SURFACE ROUGHNESS, COMPOSITION & TEMPERATURE
- STRUCTURE & PHENOMENA OF THE UPPER ATMOSPHERE
- CLOUD STRUCTURE & COMPOSITION
- INTERACTION BETWEEN SEA SURFACE & ATMOSPHERE
- SPECTRAL, SPATIAL & TEMPORAL CHARACTERISTICS OF SIGNIFICANT FEATURES OF THE EARTH'S SURFACE

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Figure 24

The Nimbus program, designed to further technology in the meteorological satellite program, is restricted to lower altitude orbits. Therefore, we have under consideration a meteorologically-dedicated ATS satellite, called MET-ATS planned for launch in 1974. This satellite is being proposed to adapt quantitative measurements of the atmospheric structure to geostationary surveillance technology. This combination would enable us to obtain variable-time-scale or nearly continuous soundings of selected portions of the atmosphere.

The value of the Nimbus program to the field of meteorology, and to the quantitative measurement objective, cannot be overemphasized. Nimbus III, the current satellite of this program, now in orbit, has been hailed as one of the most important developments in the history of meteorology. Figures 25 through 31 will briefly illustrate the data products obtained from Nimbus III, clearly demonstrating the reasons for the high regard for this satellite.

Nimbus III contains two infrared sounders for the quantitative measurement of the atmospheric structure--the SIRS and the IRIS. Figure 25 shows the SIRS- and IRIS-derived temperature structure of the atmosphere, as obtained from Nimbus III, compared with a standard measurement by radiosonde. The comparison is excellent. The upper circle has the 300 MB contour, constructed from Nimbus III SIRS data and the lower circle is that constructed from conventional data. The similarity of the patterns attests to the usefulness of satellite sounding data. Also shown on Figure 25 is a montage of daytime cloud cover provided by an IR imagery system. Figure 26 depicts the principle and the products of the IRIS. This instrument utilizes the entire spectrum, and as such represents a more versatile instrument. From radiation values in

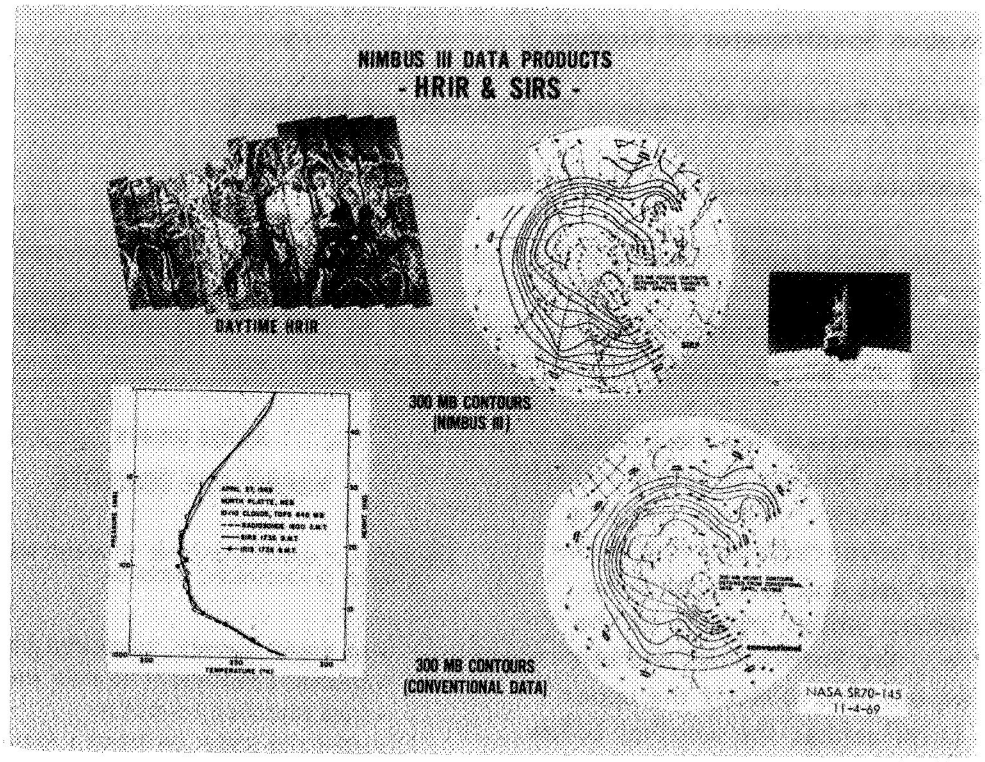

Figure 25

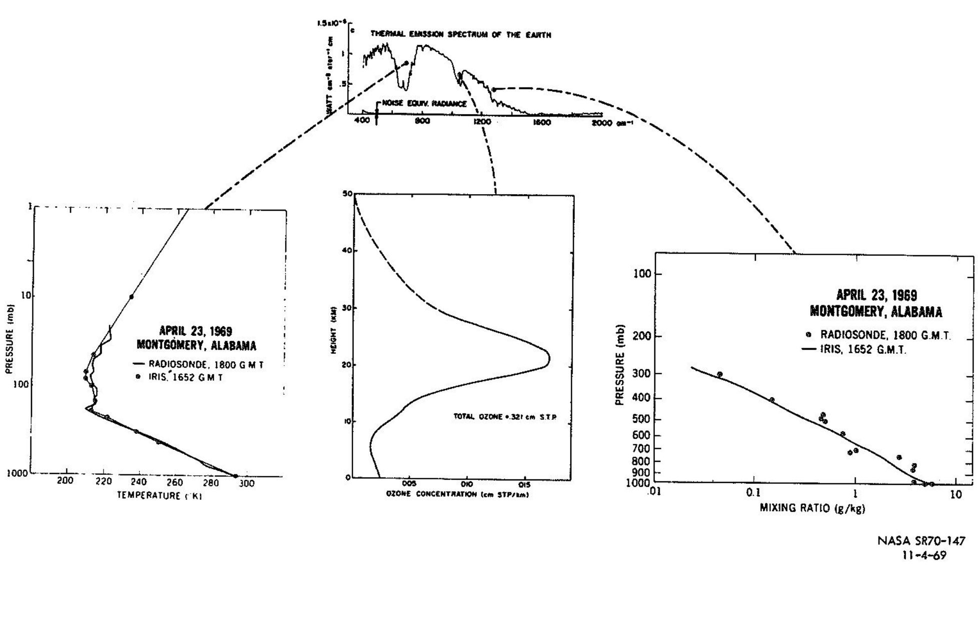

Figure 26

this spectrum we can deduce the temperature, as shown in the left graph, the total atmospheric ozone content, shown at the bottom center and the water vapor mixing ratio, shown in the graph at the lower right.

The additional Nimbus III data products (Figure 27) come from the High Resolution Infrared Radiometer (HRIR), the Medium Resolution Infrared Radiometer (MRIR) and the Monitor of Ultraviolet Solar Energy (MUSE).

The HRIR provides us with nighttime viewing of the cloud cover and also, during daylight, with mapping of the reflected solar IR radiation, useful in showing contrasts between deserts, vegetation, and water surfaces.

The MRIR is a 5-channel radiometric device covering the water vapor band at 6.5 to 7 microns, the radiation transparency band, or "window" from 10 to 11 microns, the carbon dioxide channel from 14.5 to 15.5 microns; the water vapor rotational bands from 20 to 23 microns, and visible and near-IR radiation from 0.2 microns to 4 microns. These data are used separately and together in atmospheric research.

The MUSE is designed to measure the variations in solar radiation by looking at the Sun and determining whether there are variations in this part of the solar spectrum which can be seen only from above the atmosphere. If these variations exist, we will attempt to correlate them with changes in the upper atmosphere. Early results suggest that significant variation can be measured in the shortest of the wavelength bands -- 1200 Å.

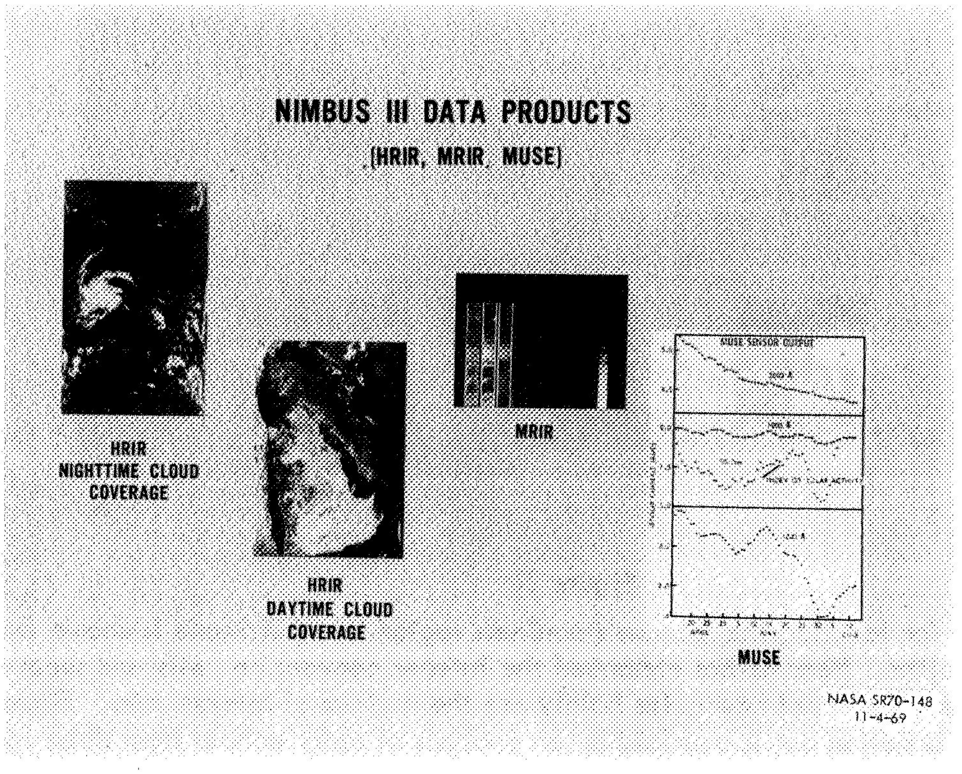

Figure 27

Figure 28 shows the sequence of photographs of Hurricane Camille, as tracked by Nimbus III. The first identification of this storm was made using the photograph made on 11 August 1969. The clarity and detail of these photographs are striking. By 16 August we could see the distinct eye of Hurricane Camille associated with this very intense and dangerous storm with winds of 160 miles per hour. On Sunday, 17 August, Camille was 250 miles south of Mobile, Alabama, and the Weather Bureau was advising preparation for heavy storms. Some residents had already started boarding up residences and businesses and moving north out of the path of the storm. The eye of Camille moved inland just west of Bay St. Louis, Mississippi, about 11:30 p.m. that night. Camille continued to move north and northeast as an identifiable precipitation pattern on 18 and 19 August, weakening steadily with rains of only one to two inches in Southern Kentucky. Arriving at the Appalachian Mountains in the late hours of 19 August, the storm intensified rapidly and turned to the east. In an eight-hour period, rainfall of 12 to 14 inches was fairly widespread in the mountains and amounts exceeding 27 inches occurred in one area; more than three times the state's previous record of 8.4 inches in 12 hours.

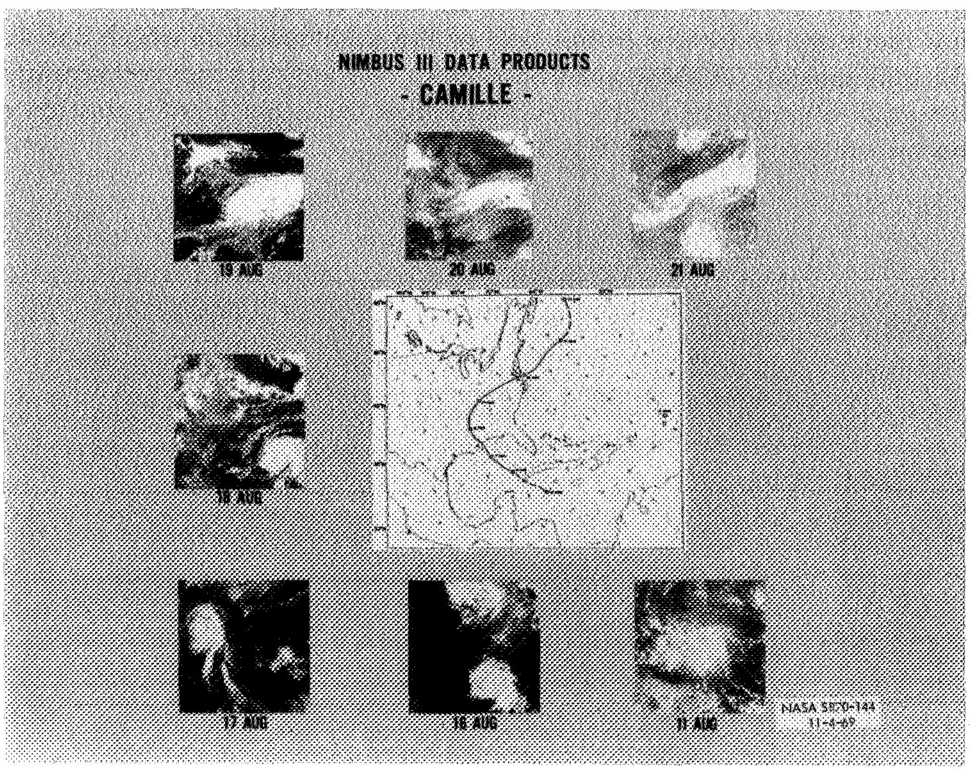

Figure 28

Another technique for locating the intense storminess region in a hurricane is shown on Figure 29 prepared by Dr. Fujita. Here he has enhanced the intense convection cells and suppressed the other cloud regions. Depicted now quite boldly are the regions of intense rain. Figure 30 has the same Fujita information but is overlaid by an analysis of radar echoes from three radar sites. These echoes show only areas of intense rain. Note how nicely the Fujita technique isolates the areas of intense precipitation. At the same time we see how much greater coverage is provided by the satellite photos.

ENHANCED PHOTO

CAMILLE

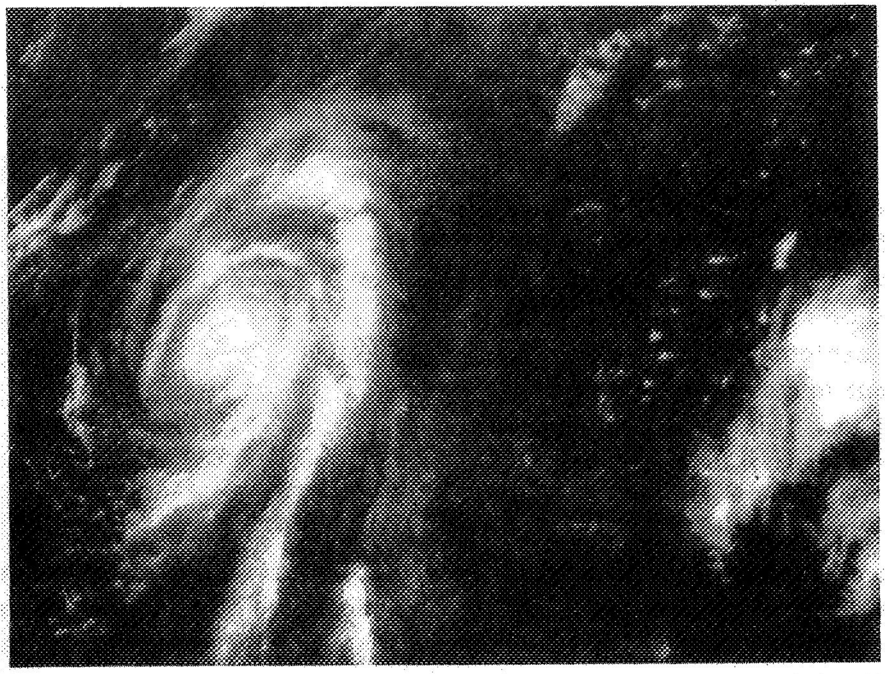

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Figure 29

ENHANCED PHOTO

CAMILLE

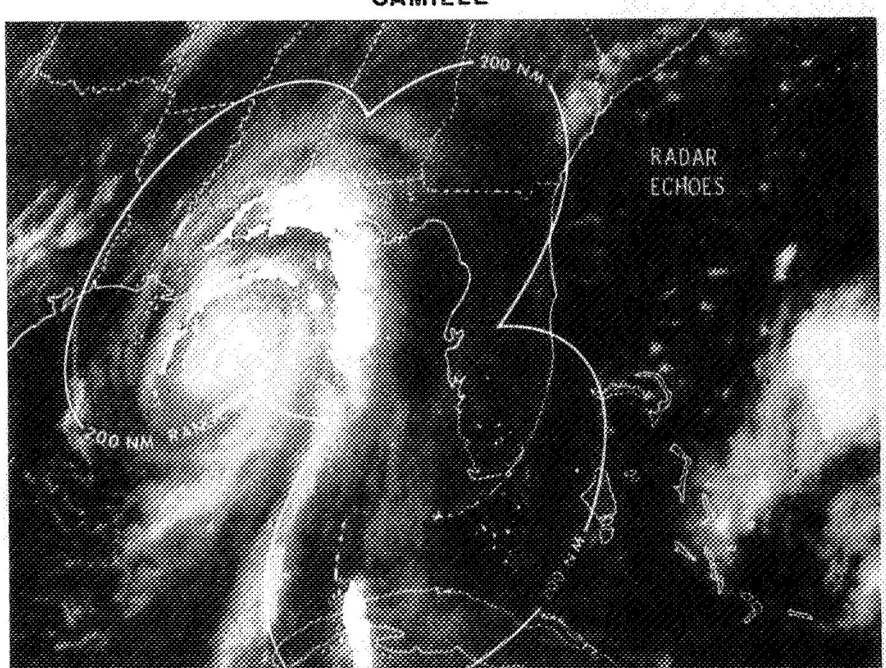

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Figure 30

Figure 3l depicts the Interrogation, Recording and Location System (IRLS) flown on Nimbus III. This is a communications and position location system for meteorological purposes, which enables us to interrogate world-wide platforms, receive data from those platforms, and to determine the location of the platform. This information is stored in the satellite memory for delivery to the data acquisition station. Examples of sensor platforms which have been used with this system are included on Figure 3l. One platform which may require explanation is the elk--this represents an attempt to track the migration of an animal by satellite. This is the only experiment shown here that has not as yet been performed.

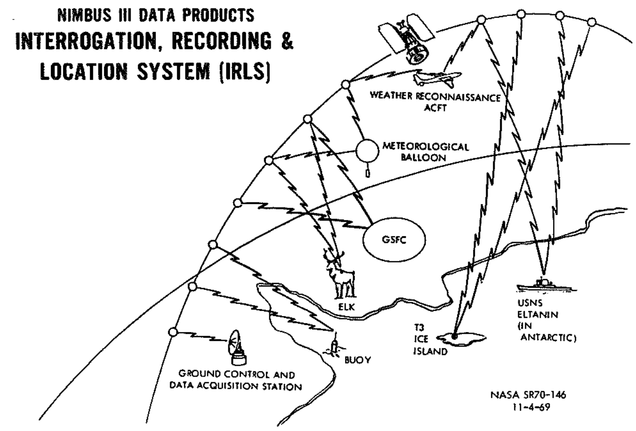

Figure 31

In summary, the data products from Nimbus III show the spacecraft and its experiments to be significant in the history of meteorology. For the first time, we have conducted remote sounding from a spacecraft, and even with this first spacecraft have found the results applicable to operational problems.

Figure 7 was used earlier to show the evolution of the meteorological program from TIROS, the first meteorological satellite, to a period in the mid-1970's. Let us now come back and discuss GARP. As mentioned earlier, GARP is an acronym for Global Atmospheric Research Program.

The GARP story (Figure 32) commenced in the early 1960's shortly after the historic launch of the first of the TIROS satellites. Recognition of the tremendous potential of observations from space led to early efforts to employ space to man's benefit. The late President Kennedy, in an address to the United Nations in 1961, stated, "We shall propose further cooperative efforts between all nations in weather prediction and eventually in weather control."

The United Nations, "Noting with gratification the marked progress for meteorological science and technology opened up by the advances in outer space...," recommended in 1961 the early and comprehensive study of measures to employ space observations to advance the state of atmospheric sciences. The U.N. further proposed, in 1962 that a detailed plan to strengthen meteorological services and research be developed placing particular emphasis upon meteorological satellites.

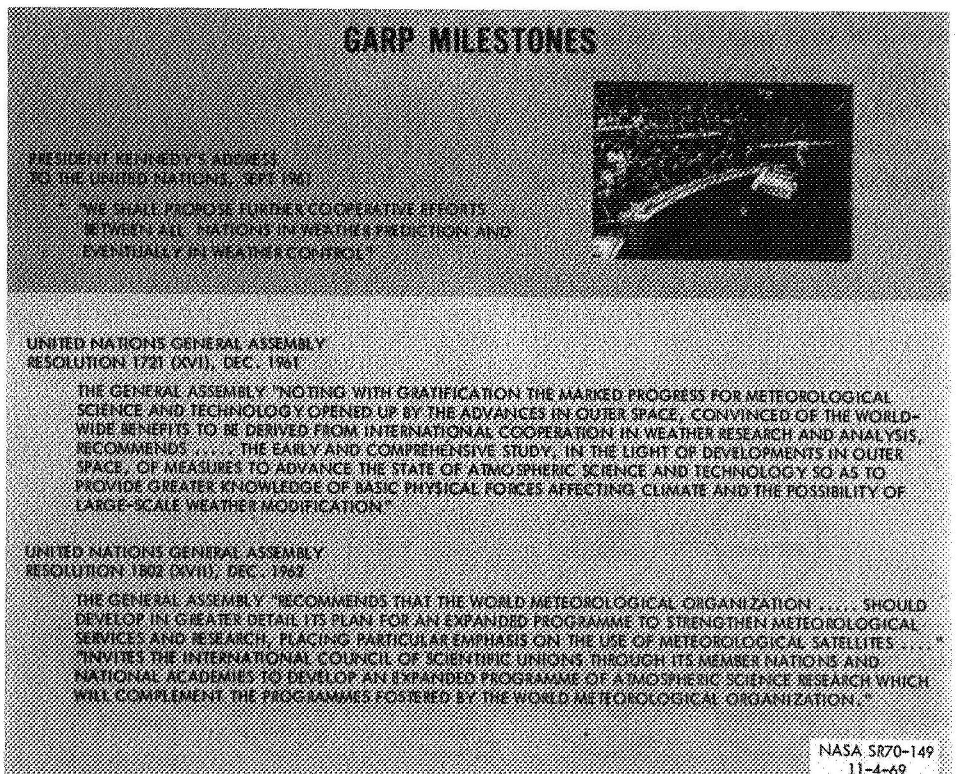

Figure 32

In response to these proposals, the scientific community has investigated the manner and extent to which meteorological satellites could contribute to the advancement of our knowledge and understanding of the weather. Studies revealed clearly that weather, as we noted earlier in

Figure 4, is global, and that conditions prevailing over one sector of the globe will have definite influence on other sectors. Moreover, other studies (Figure 33) indicate that extensive requirements for weather data are needed for accurate weather forecasts. The most modest of l to 2-day forecasts require longitudinal and latitudinal coverage of several thousand miles and vertical coverage from the Earth's surface to the tropopause. To be able to extend our forecasts in time beyond l to 2 weeks will require knowledge of weather and weather-influencing phenomena covering nearly the entire globe from pole to pole and to the depths of several meters in the oceans.

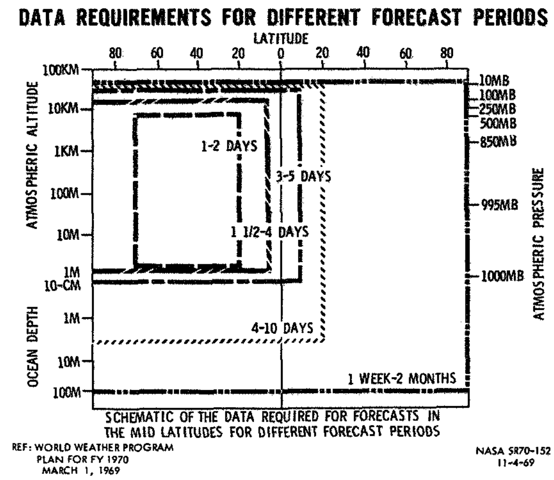

Figure 33

The GARP concept evolved and is based on the accomplishments of three separate technological programs, as indicated on Figure 34. Present theory and technology enable us to forecast the weather with reasonable accuracy for 24 to 48 hours in advance. We have been engaged in theoretical and applied meteorological research which has produced mathematical models of atmospheric behavior. It has been shown that integration of these mathematical equations with time will provide a forecast of

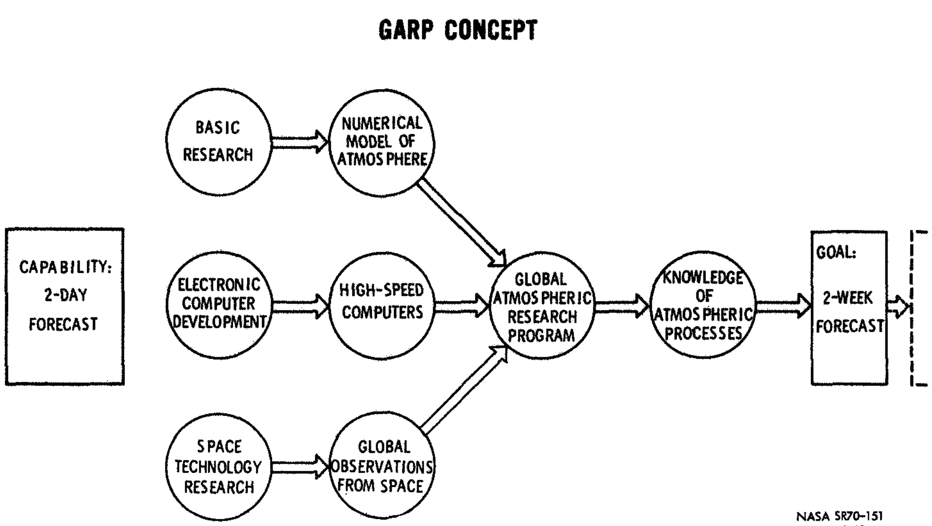

Figure 34

future weather conditions. However, the complexity of the mathematical model is too great for manual manipulation, and also the models require global data for the initial conditions. Fortunately, electronic computer development has produced high-speed computers capable of handling the numerical models of the atmosphere, and space technology research puts us on the threshold of obtaining global quantitative observations of the atmosphere. Therefore, we can see the opportunity to combine these three major breakthroughs--numerical models, high-speed computers, and global observations--into one concerted global atmospheric research program. From this program we hope to achieve a scientific understanding of atmospheric processes plus the operational techniques for applying this understanding, producing a forecast

GARP MILESTONES

SEP 1961	PRESIDENT KENNEDY IN SPEECH TO UN, PROPOSED COOPERATIVE EFFORT IN WEATHER PREDICTION & CONTROL
DEC 1961	UN GENERAL ASSEMBLY ADOPTED RESOLUTION 1721 (XVI)
DEC 1962	UN GENERAL ASSEMBLY ADOPTED RESOLUTION 1802 (XVII)
1963-1967	NATIONAL AND INTERNATIONAL PLANNING ACTIVITIES
OCT 1967	ICSU/WMO ESTABLISHED THE JOINT ORGANIZING COMMITTEE (JOC)
NOV 1967	NATIONAL ACADEMY OF SCIENCES APPROVED A U.S. COMMITTEE FOR GARP
MAY 1968	U.S. CONGRESS PASSED CONCURRENT RESOLUTION ENDORSING THE WORLD WEATHER PROGRAM
JULY 1968	PRESIDENT JOHNSON MEMO CALLED UPON AGENCIES TO COOPERATE FULLY IN THE WORLD WEATHER PROGRAM
MAR 1969	PRESIDENT NIXON SUBMITTED FIRST PLAN TO CONGRESS FOR U.S. PARTICIPATION IN WORLD WEATHER PROGRAM
MAY 1969	WMO EXECUTIVE COMMITTEE APPROVED DRAFT JOC PLAN FOR GARP
MAY 1969	ICSU PANEL FOR GARP APPROVED DRAFT JOC PLAN FOR GARP
JUNE 1969	U.S. COMMITTEE FOR GARP (USCG) PUBLISHED PLAN FOR U.S. PARTICIPATION
MAR 1970	INTERNATIONAL PLANNING MEETING OF NATIONS TO EXPRESS INTEREST AND DEGREE OF PARTICIPATION

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Figure 35

which other studies show would be valid for up to two weeks, and possible leading to a capability to modify weather conditions to man's benefit.

Figure 35 lists chronologically some of the major milestones in the GARP program. We have covered the first four items on the conception and early studies for the program. The next item, the establishment of national and international organizations representing both the scientific community and the governments of the participating nations, is outlined in Figure 36. Congress, former President Johnson and President Nixon supported the

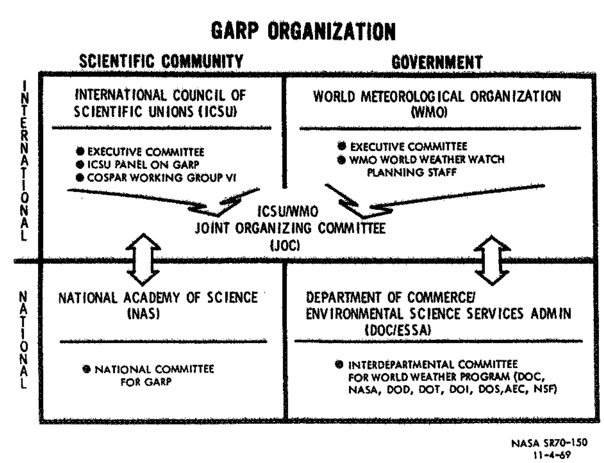

Figure 36

planned program. President Nixon in March of 1969 submitted to Congress the first plan for U.S. participation in the World Weather Watch, as mentioned at the beginning of this presentation.

Planning for this research program has been focused on specific data requirements. Figure 37 lists the observational requirements, summarizing the weather parameters and their specifications. In terms of these requirements, it can be seen from the map in Figure 37 that while data from portions of the temperate zones of North America, Europe and Asia are adequate, data from the rest of the world is generally inadequate for our purposes. The current concept to provide global data by satellites during the 1974-1975 time frame is shown on Figure 38. This concept calls for a combination of four geostationary satellites for detailed surveillance of the lower and mid-latitudes, two polar orbiting satellites for surveillance of the polar regions, and low-altitude equatorial orbiting satellites for tropical wind data.

These actions take us through May 1969. In June 1969, the U.S. Committee for GARP published the plan for U.S. participation in GARP. Figure 39 summarizes the proposed U.S. subprograms to study the physical processes of vital concern to GARP. These include plans for developing the global observing capability, programs for studying meteorological processes, and experiments to improve numerical prediction equations. The field observations programs proposed as part of this program are listed on Figure 40. The first two programs have been conducted, and the remainder will be carried out in conjunction with the development of the observing capability. The tropical cloud cluster experiment and the global observing system Pacific test are experiments of major magnitude, i.e., comparable in size and importance to the recent BOMEX experiment.

GLOBAL OBSERVATIONAL REQUIREMENTS FOR GARP

- WIND VELOCITY ±3 MPH
- TEMPERATURE ±1°C
- WATER VAPOR ±10%
- PRESSURE ±0.2%
- HORIZONTAL RESOLUTION 400 KM
- VERTICAL RESOLUTION 200 MB
- HORIZONTAL DOMAIN GLOBAL
- VERTICAL DOMAIN SURFACE TO 10 MB
- FREQUENCY ONCE PER DAY

CURRENT AVAILABILITY OF UPPER-AIR DATA:

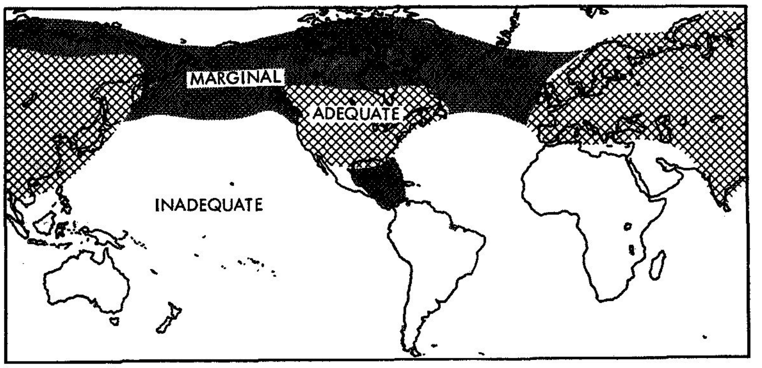

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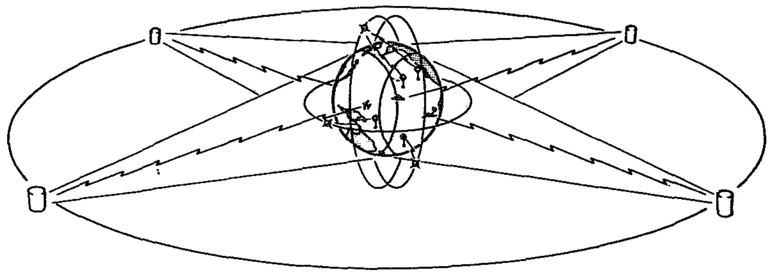
Figure 37

CURRENT CONCEPT OF GLOBAL SATELLITE OBSERVING SYSTEM, 1974-75



GEOSTATIONARY SATELLITES (4)
- VISIBLE & IR SCANNERS (WINDS)
- IR SPECTRO-RADIOMETERS (TEMP)
- TWO-CHANNEL RADIOMETERS (CLOUDS)
- TRANSPONDERS (DATA COLLECTION)

POLAR ORBITING SATELLITES (2)
- SATELLITE-BALLOON LOCATION SYSTEM (WINDS)
- IR AND MICROWAVE SPECTRO-RADIOMETERS (TEMP & WATER VAPOR)
- TRANSPONDERS (DATA COLLECTION)

LOW INCLINATION ORBITING SATELLITES
- SATELLITE-BALLOON LOCATION SYSTEM (WINDS)

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Figure 38

PROPOSED U.S. SUBPROGRAMS TO STUDY THE PHYSICAL PROCESSES OF VITAL CONCERN TO GARP

PROGRAMS FOR DEVELOPING THE GLOBAL OBSERVING CAPABILITY
- OBSERVING SYSTEMS SIMULATION EXPERIMENTS
- GLOBAL OBSERVING SYSTEMS PACIFIC TEST

FIELD OBSERVATIONAL PROGRAMS FOR STUDYING PHYSICAL PROCESSES
- TROPICAL CLOUD CLUSTER EXPERIMENT
- BOUNDARY LAYER AND CONVECTION EXPERIMENTS
- CLEAR AIR TURBULENCE EXPERIMENTS

NUMERICAL MODELLING EXPERIMENTS FOR IMPROVING THE PHYSICAL FORMULATION OF THE PREDICTION EQUATIONS
- NUMERICAL MODELLING EXPERIMENTS

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Figure 39

GARP FIELD OBSERVATIONS PROGRAMS
(RECOMMENDED BY NAS GARP COMMITTEE)

1967	LINE ISLAND EXPERIMENT	CENTRAL PACIFIC
1969	BOMEX	BARBADOS
1970	TRADE WIND INVERSION	EASTERN TROPICAL PACIFIC
1970-73	CLEAR AIR TURBULENCE	CENTRAL & WESTERN U.S.
1970-71	STRONG AIR MASS MODIFICATION	OFF U.S. EAST COAST
1972	LAND CONVECTION BOUNDARY LAYER	CENTRAL U.S.
1973	TROPICAL CLOUD CLUSTER	MARSHALL ISLANDS
1973	GLOBAL OBSERVING SYSTEM - PACIFIC TEST	PACIFIC OCEAN
1974	"POPCORN" CUMULUS	AMAZON BASIN (TROPICAL CONTINENTAL)
1974-75	GLOBAL GARP	GLOBAL

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Figure 40

The immediate future also contains milestones of significance to GARP. During the next few months, we will be developing the U.S. position for the International Planning Meeting of nations who will meet to express interest and to discuss possible participation in GARP. Also of importance is the World Meteorological Organization (WMO) Quadrennial Congress in 1971, which will establish the WMO budget for the following four years.

This concludes our discussion of GARP. It represents a program of great significance to the meteorological community, and is a program to which NASA can, and should, make a major, vital contribution. In recognition of this importance, we have established a GARP Project Office at the Goddard Space Flight Center (GSFC) to insure timely and adequate input from NASA to the planning and development of the GARP program.

In the development of the Meteorological Satellite Program, NASA plays an important and dynamic but not independent role. The design, development and scheduling of the entire Meteorological Satellite Program (Figure 41) is coordinated directly on a bilateral basis with ESSA through the coordinating bodies of the Meteorological Satellite Program Review Board (MSPRB) and the Advisory Group for Supporting Technology for Operational Meteorological Satellites (AGSTOMS). Direct formal coordination with the Department of Defense is accomplished via the Subcommittee on Meteorology of the Unmanned Spacecraft Panel. Direct coordination also occurs between ESSA and DOD. However, no formal body has been established for this express purpose. In addition, multi-agency coordination of meteorological satellite research, development and operations is conducted through the functioning of the Interdepartmental Committee on Atmospheric Sciences (ICAS), Interdepartmental Committee for Applied Meteorological Research (ICAMR), and the Interdepartmental Committee for Meteorological Services (ICMS).

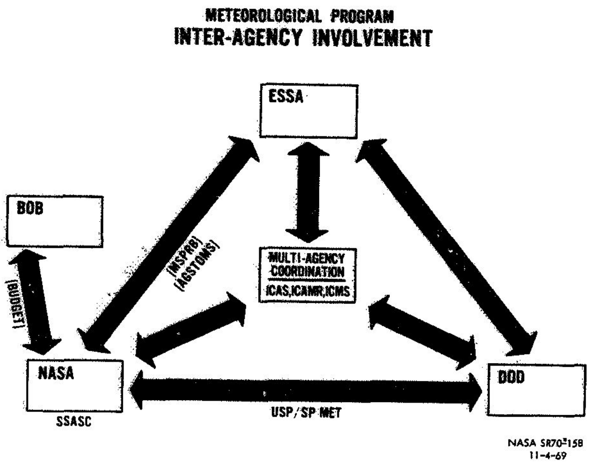


Figure 41

As one would expect, our universities play an important role in the development and conduct of the Meteorological Satellite Program. NASA has made extensive use of the technical capabilities to be found in engineering and scientific colleges. As we can see from Figure 42,

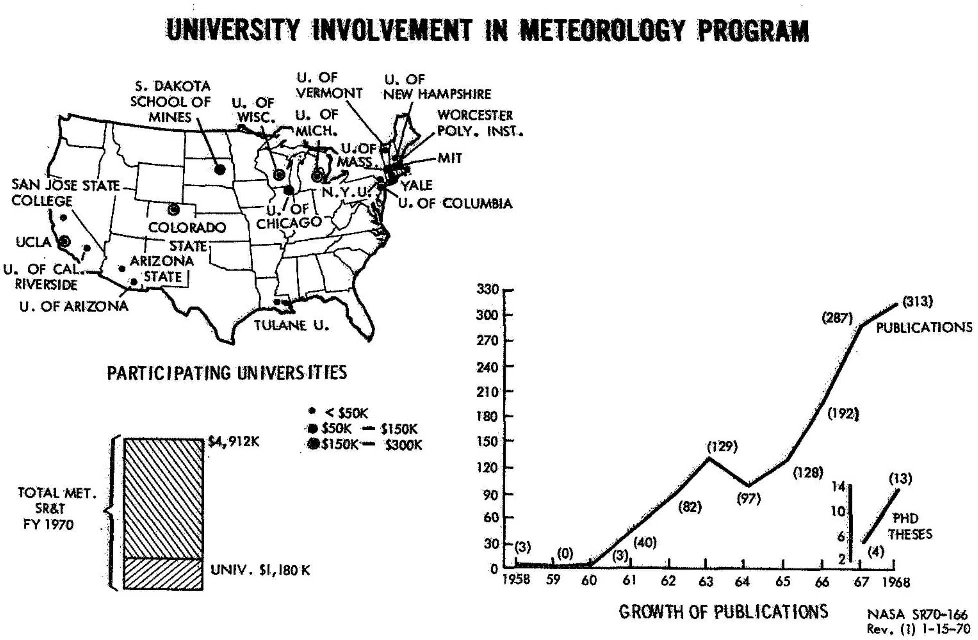


Figure 42

there are about 20 educational institutions now participating in this program, distributed as indicated. During FY 1970 we have funded $4,912,000 in Supporting Research and Technology (SR&T); of this total, $1,180,000 has gone to universities. Also of note is the interest in satellite meteorology throughout the meteorological community as suggested by the number of publications dealing with this subject. These have grown to more than 300 per year in the ten short years of space experience. The number of PhD theses dealing with satellite meteorology also reflects an increasing interest.

An excellent example of the explosive growth in both interest and participation is the University of Wisconsin story (Figure 43). In the early years there was essentially only a single investigator, Professor Suomi, concerned with acquiring and interpreting radiation data from space. This led to increased interest at the University of Wisconsin in the Earth's radiation balance, the variations in the Earth's radiation budget, development of IR sensors and research into atmospheric effects on reflection, transmission and emission of radiation. In short, a center of excellence in this field developed there. Recognition of this institution as a center of excellence has led directly to increased emphasis upon the field of meteorology and also has resulted in expansion of interests into the multi-disciplinary impacts of satellite meteorology on agriculture, commerce, communications, economics and even social and political studies. In this manner, the University of Wisconsin has assisted the total Meteorological Satellite Program and has reaped considerable benefit and world-wide recognition as a center of excellence in this field.

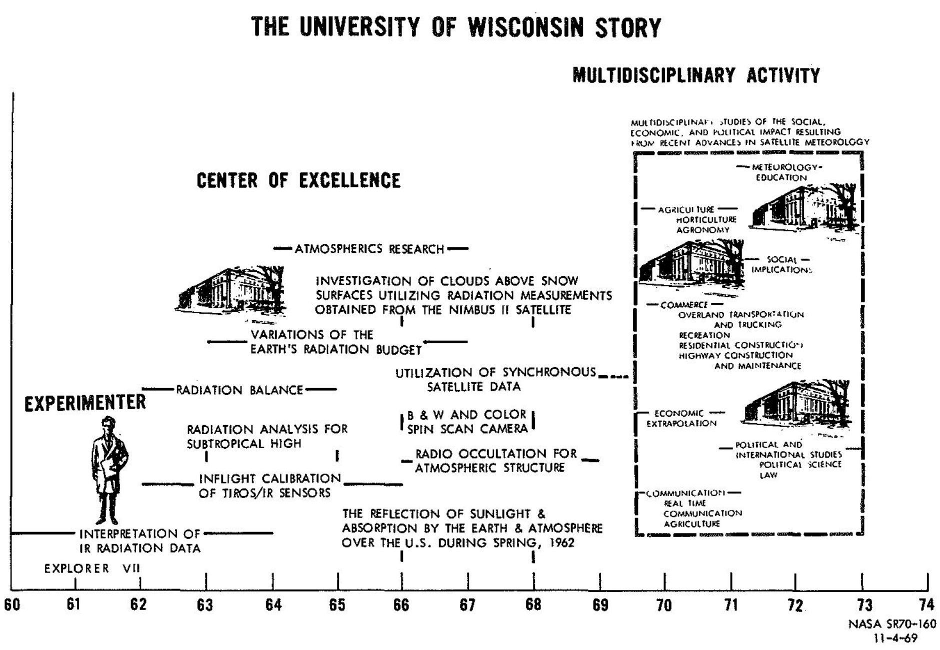


Figure 43

Finally, a brief word on personnel and funding requirements. Figure 44 presents the current and projected funding level and personnel requirements by field center. The bulk of the requirements, both for funds and for personnel, are found at Goddard Space Flight Center, where the TIROS, TOS, ITOS, Nimbus and synchronous satellite programs are executed. Other centers also contributing to these programs, but at a considerably lower level, include the Jet Propulsion Laboratory (JPL), the Electronics Research Center (ERC), the Langley Research Center (LaRC), and Wallops Station (WS). The total NASA in-house personnel figures range between 200 to 250. All of the data includes requested Fiscal Year 1971 new starts and run-out of existing programs and the new starts.

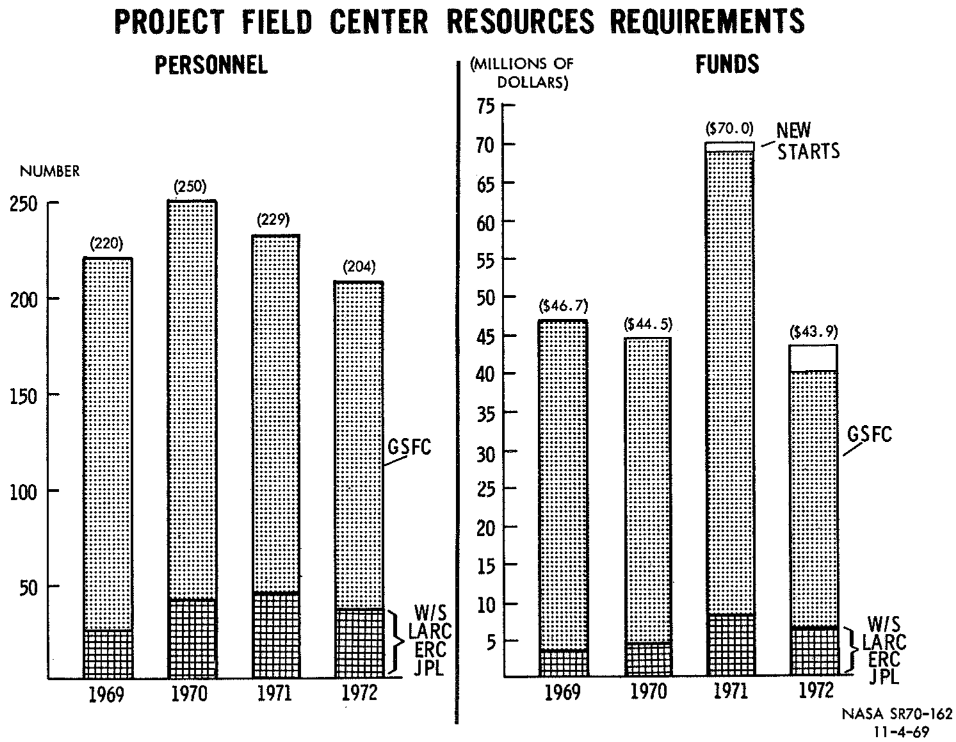


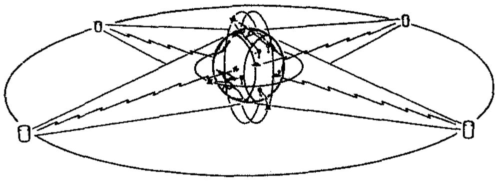
Figure 44

As we stated at the beginning of this presentation (Figure l) our goal is to understand the physics of the atmosphere, to bring about improved prediction of weather, and to establish a basis for eventual weather modification and climate control. The Meteorological Satellite Program provides valuable contributions toward this goal. Figure 45 lists some major recent accomplishments of our national Meteorological Satellite Program. We have achieved continuous operation of a system providing daily cloud cover photographs, locally and globally. We have engaged in the planning, research and development of the GARP, with such activities as the BOMEX experiment, the World Weather Program plan, and the U.S. plan for participation in GARP; and we have accomplished the first quantitative measurements of the structure of the atmosphere from space, with the highly-successful Nimbus III satellite.

METEOROLOGICAL PROGRAMS

SIGNIFICANT ACCOMPLISHMENTS

- CONTINUOUS OPERATION OF THE NATIONAL OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM
  - DAILY GLOBAL CLOUD COVER PHOTOGRAPHS
  - DAILY LOCAL CLOUD COVER PHOTOGRAPHS
- PLANNING, RESEARCH & DEVELOPMENT OF THE GLOBAL ATMOSPHERIC RESEARCH PROGRAM
  - BOMEX EXPERIMENT
  - WORLD WEATHER PROGRAM PLAN
  - US PLAN FOR PARTICIPATION IN GARP
- QUANTITATIVE MEASUREMENTS OF THE STRUCTURE OF THE ATMOSPHERE FROM SPACE (NIMBUS III)
  - VERTICAL PROFILE OF TEMPERATURE
  - VERTICAL PROFILE OF WATER VAPOR
  - VERTICAL PROFILE OF OZONE CONTENT
  - SOLAR FLUX MEASUREMENTS
  - INTERROGATION, RECORDING, & LOCATION OF FIXED & FREE-FLOATING SENSOR PLATFORMS



NASA SR70-200
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Figure 45

EARTH OBSERVATIONS PROGRAMS REVIEW

CONCLUDING REMARKS

Presented by
Mr. Leonard Jaffe

There are many facets to the Earth Observations satellite program which are common to the whole space applications effort. Some are being well handled, others require much more attention. I should like to conclude this program review with a listing of some of the activities which must be attended to, if NASA is to meet potential responsibilities and opportunities afforded by the applications of space.

We are all familiar with the applications currently recognized as space applications: Communications, Navigation, Traffic Control, Earth Physics, Geodesy, Meteorology and Earth Resources. The latter, Earth Resources, should really be discussed in terms of its constituent elements of Agriculture/Forestry, Geography/Cartography, Geology, Hydrology and Oceanography. If we are to fully develop these applications, we must develop within NASA adequate understanding of these subjects and their problems in order to be able to provide the appropriate and realistic guidance regarding the potential applications of space to each. It has become increasingly clear to us that we must have within NASA a minimum capability in each of these areas to direct and influence the development within the user community. To do this effectively requires that we have an understanding of their problems and needs. This requires personnel expert in the user disciplines.

The flight programs are many and diverse: ATS, GEOS, Nimbus, TIROS, SMS, ERTS, SATS, NAV/TC, a sounding rocket program and an aircraft program; the support of operational programs such as INTELSAT, TOS/ESSA and future operational systems, our involvement in manned missions and in large scale environmental experiments such as BOMEX, TROMEX and eventually GARP. We have done reasonably well in the past with minimal NASA support for such programs, but, as the programs grow in complexity and number and our involvement deepens, NASA personnel commitments must also grow.

We must expand our cost-benefit studies in all areas, not only to more fully understand the justifications for each NASA-requested mission, but to more fully understand the appropriate realistic role of satellites and to better direct our R&D efforts. We must expand our conceptual systems study efforts not only to insure that we are selecting the right R&D mission for the NASA program, but to put NASA in the posture of the "National Space Expert" who can advise the concerned elements of government not only with respect to technical feasibility of particular approaches but with advice as to preferred approaches in the national interest. As an example, we have a legislated responsibility to advise the Federal Communications Commission (FCC) and the Department of State on the subject of communications satellites. Until now our advice has been restricted to a commentary on the technical feasibility of a proposal made by COMSAT to the FCC. The FCC has told us that this is not sufficient. They want advice from NASA, not only on technical feasibility but on whether the particular system being proposed is the best system that can be established at any particular time taking into account all aspects of the Nation's interests.

The study of preferred approaches involves more than technical considerations. Social, economic, organizational, and political considerations are a part of the whole. We must involve appropriate talent within NASA on such considerations as well as expand our university involvement in these questions. I believe an example of a good way to go about this is contained in our approach to the University of Wisconsin where we are building on the technical competence of an individual to involve other disciplines of the University in thinking about all aspects of a particular problem. We shall want to expand this type of experiment to other universities and other applications. We are working with the University of California to try to develop such a concept and program in Earth Resources Surveys.

We have just begun to scratch the surface of the problems of data management--for processing, formating and distribution. We must begin to consider organizational roles and jurisdictions and responsibilities as well as the development of techniques and hardware. NASA will be called upon for advice in these matters. An important consideration in these problems will be industrial and commercial relationships.

We must consider our role in providing for orientation and training of other user agencies and of foreign nationals. President Nixon's statement to the United Nations on Earth resources carries with it a potential commitment to involve our international neighbors on a much more expanded scale. The cooperative efforts with Mexico and Brazil are experiments; we should learn from them and plans for the future should be developed, taking this experience into account. However, we should not necessarily consider these efforts as necessarily adequate patterns for the future.

The international involvement will grow in other applications as well, for example, NAV/TC, Oceanography, etc. As the budgets tighten in all countries, the interest has turned to applications of space, which, in the eyes of many, can be justified on the more immediate return on investment.

The interest in the applications program at national, state and local levels continues to grow and will require respective individual thought and attention.

The pressure for improved radio frequency spectrum management directions will derive largely from the frequency allocation requirements for the new applications of space, i.e., ERS, NAV/TC, data collection, etc. NASA inputs are required. Consideration must be given to interference limitations, space technology developments, systems concepts, and the need to study ways to conserve the spectrum. As a nation, we must investigate, understand and prepare our position on a much earlier time scale for national and then international endeavors such as the World Administrative Radio Conference (WARC) sponsored by the International Telecommunications Union (ITU).

Finally, we have the attention of many people and many activities. This may be viewed as fortunate or unfortunate, depending on one's point of view. The following groups are already involved:

President's Scientific Advisory Committee (PSAC)
Office of Science and Technology (OST)
Bureau of the Budget (BOB)
National Aeronautics and Space Council
National Council for Marine Research and Engineering Development
National Academy of Science
Department of Interior (USGS)
Department of Agriculture
Department of Commerce (ESSA)
Department of the Navy (NAVOCEANO)
Congress, Congressional Committees and Staffs
The Oceanographic Community
The Press
Engineering Societies

There are many more that I could name, but the point that I should like to make is that the interested and concerned community is large, and every element of this community desires and deserves the attention of NASA on the subject of their interest. Applications of space are topics of intense interest and concern to these people, and the amount of time that must be devoted to these interests is inordinately high relative to the proportion of the space R&D budget consumed.

All of these factors must be recognized in the allocation of personnel resources to space applications efforts, both at NASA Headquarters and the field centers. The field centers must be made to understand the need for an expenditure of valuable talent on studies which may never result in a NASA space flight, and Headquarters must recognize the need to involve itself in the concerns of space applications at the very highest levels to insure adequate and timely policy attention.

ABBREVIATIONS AND ACRONYMS

Å	Angstrom (10^{-8} centimeters)
ACFT	Aircraft
AEC	Atomic Energy Commission
AGSTOMS	Advisory Group on Supporting Technology For Operational Meteorological Satellites
APT	Automatic Picture Transmission Camera system
ATS	Applications Technology Satellite
AVCS	Advanced Vidicon (television) Camera System
BOB	Bureau of Budget
BOMEX	Barbados Oceanographic Meteorological Experiment
BUV	Backscatter Ultraviolet (UV) Spectrometer sensor
CM	Centimeter
COMSAT	Communications Satellite Corporation
DCS	Data Collection System
DOA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
DOS	Department of State
DOT	Department of Transportation
DWS	Dry Workshop (Apollo Applications)
ERC	Electronic Research Center
ERS	Earth Resources Survey
ERSPRC	Earth Resources Survey Program Review Committee
ERTS	Earth Resources Technology Satellite
ESMR	Electronically Scanning Microwave Radiometer sensor
ESSA	Environmental Science Services Administration
FCC	Federal Communications Commission
FWS	Filter Wedge Spectrometer sensor
GARP	Global Atmospheric Research Program
GEOS	Geodetic Satellite
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center (NASA, Greenbelt, Maryland)
HRIR	High Resolution Infrared (IR) Radiometer sensor
ICAS	Interdepartmental Committee on Atmospheric Science
ICAMR	Interdepartmental Committee on Applied Meteorological Research
ICMS	Interdepartmental Committee on Meteorological Services
ICSU	International Council of Scientific Unions
IDCS	Image Dissector Camera System
IMC	Image Motion Compensation
INTELSAT	International Telecommunications Satellite
IR	Infrared
IRIS	Infrared Interferometer Spectrometer sensor
IRLS	Interrogation, Recording and Location System

ITOS	Improved TIROS Operational (satellite) System
ITU	International Telecommunications Union
ITPR	Infrared Temperature Profile Radiometer sensor
JOC	Joint Organizing Committee (ICSU/WMO)
JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center (NASA, Hampton, Virginia)
LV	Launch Vehicle
MB	Millibar (unit of atmospheric pressure)
MET-ATS	Meteorological ("dedicated") Applications Technology Satellite
MHZ	Megahertz
MGS	Multi-detector Grating Spectrometer sensor
MRIR	Medium Resolution Infrared Radiometer sensor
M/S	Multi-Spectral
MSC	Manned Spacecraft Center (NASA, Houston, Texas)
MSPRB	Meteorological Satellite Program Review Board
MSPS	Multi-Spectral Point Scanner
MUSE	Monitor of Ultraviolet (UV) Solar Energy sensor
MWS	Microwave Spectrometer sensor
NANO-G	Acceleration of gravity constant X 10^{-9}
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAV/TC	Navigation/Traffic Control (satellite)
NDPF	NASA Data Processing Facility
NESC	National Environmental Satellite Center (ESSA, Suitland, Maryland)
NMC	National Meteorological Center (ESSA, Suitland, Maryland)
NMI	NASA Management Issuance
NSF	National Science Foundation
OPLE	Omega Position Location Experiment
OST	Office of Science and Technology (Executive Office of the President)
PCM	Pulse Code Modulation (telemetry system)
PSAC	President's Scientific Advisory Committee
RBV	Return Beam Vidicon
RDR	Realtime Data Relay
R&D	Research and Development
RTG	Radioisotope Thermoelectric Generator
SATS	Small Applications Technology Satellites
SCMR	Surface Composition Mapping Radiometer sensor
SCR	Selective Chopper Radiometer sensor
SEB	(RCA electronic tube designation)
SECOR	Sequential Collation of Range (U.S. Army geodetic satellite system)
SIRS	Satellite Infrared Spectrometer Sensor

SMS	Synchronous Meteorological Satellite
SNAP	Space Nuclear Auxilliary Power supply
S065	(Multi-Spectral Camera Experiment)
SPOC	Spacecraft Oceanography Project
SR	Scanning Radiometer
SR&T	Supporting Research and Technology
SSASC	Space Science and Applications Steering Committee
STP	Standard Temperature and Pressure
SYNCOM	Synchronous - Altitude Communications satellite
THIR	Temperature/Humidity Infrared Radiometer sensor
TIROS	Television and Infrared Observational Satellite
TOS	TIROS Operational (satellite) System
TROMEX	Tropical Meteorological Experiment (no longer planned)
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USCG	U.S. Committee on GARP
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of Interior
USGS	U.S. Geological Service
USN	U.S. Navy
WARC	World Administrative Radio Conference
WEFAX	Weather Facsimile Experiment (data transmission)
WMO	World Meteorological Organization
WS	Wallops Station research center (NASA, Wallops Station, Virginia)
Z	Zulu Time (GMT)

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